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This study on psychological traits examines three hypotheses: (1) there is a similarity between parents and their children unexplained by a similarity between the parents, (2) this similarity may be explained by hereditary components, and (3) these hereditary components are of the discrete or segregated type of inheritance. There were 104 families selected. Included in the study were the fathers, the mothers, and 58 teenage sons, and 72 teenage daughters. They were given eight psychological tests. In the 58 tests of the first hypothesis, word association was the only variable which did not show significant similarity between parent and child. In regard to the last part of the hypothesis, English vocabulary and height were the only factors which showed a significant correlation between father and mother. The second hypothesis was accepted because spatial visualization and reasoning ability showed a unique family correlation pattern. In the third hypothesis, only perceptual speed and musical aptitude clearly fulfilled the requirement that the best fits to the autosomal genetic model were approximately same percentages for the father-son distribution of scores as they were for the mother-daughter scores. Inductive reasoning showed a possibility of having an underlying dichotomy, but none of the remaining variables showed any evidence of underlying dichotomy for both father-son and mother-daughter distribution.s (DO)

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AN INVESTIGATION OF SIMILARITIES
IN PARENT-CHILD TEST SCORES
FOR EVIDENCE OF HEREDITARY COMPONENTS

by

Richard E. Stafford

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AN INVESTIGATION OF SIMILARITIES IN PARENT-CHILD TEST SCORES FOR EVIDENCE OF HEREDITARY COMPONENTS

Abstract

The general hypothesis of this study states that certain psychological traits which have their scores distributed continuously may actually have an underlying genetic dichotomy which is masked by various other effects. To be more precise, three specific hypotheses state for each variable that: (1) there is a similarity between parents and their children unexplained by similarity between the parents; (2) this similarity may be explained by hereditary components, and (3) these hereditary components are of the discrete or segregated type of inheritance.

The population, consisting of 104 fathers and mothers and their teenage sons or daughters, was given eight psychological tests: Symbol Comparison, Word Association, Mental Arithmetic, Pitch Discrimination, Letter Concepts, Spelling, Identical Blocks, and English Vocabulary. Self-reports of height and weight were also obtained. These data were analyzed both by correlational methods and dichotomic analysis. The latter is a new method designed for this study.

Parent-child correlations have previously been inadequate for investigating the presence of hereditary components in mental tests, because it is impossible to assess the degree to which the correlations are due to environmental effects. However, the transmission of a trait determined by a gene located on the X chromosome results in a unique pattern of family correlation coefficients.

Dichotomic analysis is essentially an arbitrary quartering of a bivariate distribution of parent-child scores by a successive series of artificial divisions in the continuous distributions. The frequencies observed by these arbitrary quarterings may be compared to the theoretical expected genetic frequencies by a series of chi-square goodness-of-fit tests. Should a "good fit" be found at one of the artificial divisions in the bivariate distribution of the father-son scores, and at approximately the same artificial division in the bivariate distribution of the mother-daughter scores, then an underlying dichotomy would be assumed.

To test the first hypothesis stated above, correlations between family members for each variable in the study were obtained from standard scores which partialed out the age differences in the raw scores. From these correlations, it was observed that there was only one variable, word association, which did not show a significant similarity between at least one of the parents and one of their offspring. Two of the variables, English vocabulary and height, showed a highly significant correlation between fathers and mothers which negated the second part of the first hypothesis.

The second hypothesis was accepted because two variables, spatial visualization as measured by the Identical Blocks Test and a general reasoning ability as measured by the Mental Arithmetic Test, showed a unique family correlation pattern which indicated that they have a sex-linked recessive hereditary component. Although the two tests have some variance in common, inspection of the mothers' and sons' test scores suggested that each test has an independent hereditary unit on the X chromosome.

To test the third hypothesis, each variable was subjected to dichotomic analysis. Only the Symbol Comparison Test of perceptual speed and the Pitch

Discrimination Test, a measure of musical aptitude, gave clear evidence of fulfilling the requirement that the best fit to the genetic model was approximately the same hypothesized dichotomy for the father-son distribution of scores as it was for the mother-daughter distribution of scores. The Letter Concepts Test of inductive reasoning showed a possibility of having an underlying dichotomy, but none of the remaining variables showed any evidence of an underlying dichotomy for both father-son and mother-daughter distributions.

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A number of school officials gave freely of their time and facilities to make possible the testing of the families. With profound thanks, I have listed them individually in Appendix A, but I would like to mention here, especially, the New Jersey School Development Council. I should also like to acknowledge gratefully the cooperation of the many parents and their sons and daughters who participated as subjects in this study.

With warm appreciation I wish to thank Mrs. Sally Matlack of Educational Testing Service and through her the many ETS staff members who gave generous help in the construction and printing of the test battery and invaluable suggestions in the editing, typing, proofing and printing of this dissertation.

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AN INVESTIGATION OF SIMILARITIES IN PARENT-CHILD TEST SCORES FOR EVIDENCE OF HEREDITARY COMPONENTS

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AN INVESTIGATION OF SIMILARITIES IN PARENT-CHILD TEST SCORES FOR EVIDENCE OF HEREDITARY COMPONENTS

Chapter I

INTRODUCTION AND REVIEW OF THE LITERATURE

Introduction

This dissertation is based on an investigation of familial similarities to find evidence of genetic components in mental traits. The hypothesis is made that certain traits are segregated into two categories, "present" and "not-present." The dissertation will begin with a historical survey of previous studies to point out problems which have arisen in past investigations of this type. After this review of the literature there will follow a summary of how the present study attempts to overcome some of these problems. Next, a background in genetic theory is outlined so that the techniques derived and applied in this study can better be understood. Then the variables to be investigated are discussed, the methodology explained, and the results presented with the conclusions drawn.

There has been much speculation about the antecedents of human behavior, how much of it is inherent and how much of it acquired. The "nature-nurture" controversy has been long, sometimes bitter, often futile. However, there has been a recent revival of interest in this age-old problem, and a new interdisciplinary area called "psychogenetics" or "behavior genetics" is coming into being.

It seems odd that, although genetics and psychology both had their inception in the mid-nineteenth century, they have taken so long to merge. The influence of genetics on psychology may have been checked late in the nineteenth century by two major developments: first, Watson's Behaviorism which maintained that any normal child could be trained to be successful in any undertaking, and, second, Freud's psychoanalytic theory with its emphasis upon early experiences. Although Freud, himself, believed that fixations might be traced to some innate tendency, it is his exposition of the early parental influences upon the child's psychosexual development that has predominated in psychology and much of psychiatry.

Disappointing also were some of the early data purporting to show genetic determination of behavior through descriptions of genealogies of degenerates, such as those of the Jukes (Dugdale, 1877) and the Kallikaks (Goddard, 1912). For when it was found that these infamous pedigrees were as easily reinterpreted to demonstrate the salient influence of environment, it was ruefully acknowledged that, in studying man's behavior, pedigree methods which had been proved so effective by animal breeders were here inapplicable.

The developmental influence of anthropology and sociology also seemed to retard the recognition of hereditary factors, as a wide variation of child-rearing practices, taboos, and family structures gave still further evidence of the importance of environment in determining behavior.

Later in the century, before reaction had set in to Hitler's racial myth (Dunn, 1961), a few psychologists associated with Terman at Stanford (Burks, 1928) attempted to show that a child's IQ was genetically determined. Their work was countered in turn by results from studies done at the Iowa Child Development Center (Wellman, 1945) which showed large fluctuations in the IQ's of children living under altered home conditions, and so the controversy went.

During the last 30 years, genetics has taken a new approach by rephrasing the old question, "Is it inherited or acquired?" to read, "How do hereditary factors interact with the environment to form the trait under study?" However, before a detailed answer to this problem can be given, a more pragmatic question must be answered and that is, "Does the hereditary component vary enough to be observable in the final result of the interaction?" To answer the latter question, several methods have been utilized, depending upon whether the characteristic under investigation is continuous or discrete. If it is discrete, such as blood type, family concordance between cousins or siblings would enable a test of the hypothesis that hereditary factors are present and pedigree methods might be used to determine the mode of inheritance. If the families were selected so that they contained identical and fraternal twins, nature, itself, has provided a control group, since, if it can be assumed that the environment of the twins has been relatively the same, the differences between the fraternal twins are relegated to heredity.

If the trait is a continuous one, such as height, then correlations between family members might be used. This method is effective if comparisons with correlations involving adopted or foster children are available as a control (Neel & Schull, 1954). Correlations between identical and fraternal twin members may also be compared, or the variance of the differences between twins of a pair of fraternals compared to identicals might be tested by the F ratio (Vandenberg, 1962).

There are several disadvantages in using twins. First, they are hard to obtain as subjects, and, second, there is a real problem of ascertaining their zygosity (whether they originated from a single ovum or from two ova). Third, even if evidence is found for hereditary components, no statement can be made about the mode of inheritance.

It is possible to avoid these disadvantages of the twin method by using parents and children. Families are easier to obtain, members are relatively easy to identify, and results can often give clues to the mode of inheritance. On the other hand, in studies of behavioral traits, familial correlations may be contaminated by environmental factors as Hogben (1933) points out. If this problem could be overcome, family methods would be preferable to twin methods. This study, then, will look at parent-child correlations and present a new way of interpreting some of the findings. In addition, a new method of assaying parent-child relationships has been developed and will be examined from both its theoretical point of view as well as its practical application.

Review of the Literature

It might be well first to review chronologically some of the previous studies which have used parents and children. In doing this we will restrict ourselves to those studies utilizing quantitative methods and exclude those of the pedigree type. We have also excluded studies purporting to show family influences on variables other than aptitudes or personality traits. Only studies involving humans are reviewed.

Although his statistical methods were rather crude, Galton (1869, 1880) was the first to attempt a study of inheritance of physical and psychological traits. He studied famous people and their genealogies noting the frequency with which famous ancestors appeared. This method left much to be desired in the way of controls for environmental effects, although he did compare his findings with studies of prelates of the Roman Catholic Church since they had no offspring. Among the occupations he studied were those of mathematician, scientist, statesman, and also wrestler and oarsman. He was the first to point out the advantages of studying twins. Perhaps his greatest contribution was the establishment of a laboratory for the study of human genetics and the founding of a chair to which Karl Pearson was appointed on his recommendation. In working on problems suggested by Galton, Pearson not only devised some of the most important statistical methods in use today, but he also contributed several applied studies as well. For example, he showed that correlations between parents and their children remained in the vicinity of .5 for all traits studied (Pearson & Lee, 1903), and he also pointed out that in most cases there was a great deal of selective mating between parents (for example, fathers and mothers correlate .28 in height). Selective mating (sometimes referred to as assortative mating or homogamy) must always be taken into consideration whenever a study of parents and children is undertaken, because it can seriously alter the correlation coefficients (Lush, 1945).

Pearson's studies (1903; 1910; 1918) of psychological variables (psychical variables, as he called them) left much to be desired. The ratings of these variables were clumsily made and his conclusion of the presence of hereditary influences was dubious, since he based it on comparisons with correlation coefficients found for physical traits.

Schuster and Elderton (1907) reported a correlation of .31 between fathers and sons based on scholarship ratings and offered this as evidence of inheritance. Obviously, socio-economic status, attitudes, and other environmental factors could also account for the relationship.

Cobb in 1917 measured eight families with the Courtis Standard Tests of Arithmetic. He did not report sex differences, but, since age differences were observed, parents and children were scored against their own groups. Cobb, in addition to correlating scores directly, also correlated the difference scores between performance on the various subtests. Coefficients between children's and their parents' scores ranged from .01 for subtraction to .55 for mathematics, in general. The ability to copy figures was found to correlate .45 between mid-parents' scores and their children's scores.

Moderately high parent-child correlations of pitch discrimination, a measure of music aptitude, were found by Mjoen (1925). However, his sample was not representative of the general population since the parents proved to be superior in this ability to adults in general.

One of the more comprehensive studies of similarities between parents and their children was Willoughby's (1927). He chose 11 subtests taken from the Army Beta Intelligence Test, the National Intelligence Test, and general achievement tests. They were opposites, number series completion, arithmetic reasoning, symbol-series completion, sentence meaning, geometric forms, analogies, symbol digit, science-nature information, history-literature information, and similarities checking. He used age curves to derive standard scores for all ages and kept sexes separate while doing this, but he used all pairs of parents and children in one family, i.e., a mother and her three sons were plotted three times. He found correlations ranging from .49 (uncorrected for attenuation) to .02. There were, however, relatively high correlations between mothers and fathers and he admitted that the time limits for the tests were deliberately shortened to make sure that the tests were difficult enough for the older ages.

Another extensive survey of parents and children was a study by Jones (1928) based on some rural populations from whom he obtained intelligence test scores. He used Stanford-Binet sigma scores for children and sigma scores from the Army Alpha Intelligence Test for adults, apparently assuming these tests were measuring the same thing although no correlation between them was reported. Correlations between fathers and sons compared closely with those between mothers and sons and between mothers and daughters. Jones also reported the correlations between mid-parents' scores and children's scores. The latter figures will be somewhat inflated compared to coefficients from correlations with a single parent when more than one gene is involved in the trait, since the child receives half of its inheritance from the mother and half from the father.

In a study involving foster children, Burks (1928) reported that, although there was a small positive correlation between the adopted children and their foster parents, it was not nearly as high as that between parents and their own children. It is notable that the correlation between adopted children's IQ's and ratings of the true mothers' IQ's made before adoption was very similar to that found between the parents and their own children.

Another study reported in the same volume (Freeman et al., 1928) did not find any significant difference between the correlation of foster parents' with the children's IQ's and the correlation of the true parents' with the children's IQ's.

Taking a different approach, Banker (1928) gathered data from school records in a very stable community where most of the parents and their children had gone to the same school and compared parents' school grades with those of their children. By use of a Student Ability Index,which partialed out the effects of age, Banker examined 38 families with a total of 83 children. Correlations ranged from .36 for mother-daughter to .52 for father-son. The correlation between fathers and mothers, however, was .24, showing a selection factor.

Lawrence (1931) found a low, positive correlation between foster children's intelligence and the socio-economic class of the father. Children were primarily tested with the Stanford-Binet Intelligence Test, but other tests were also used. He concluded that no generalizations about the inheritance of intelligence in social classes should be made on such low correlations.

In 1931, Conrad reviewed some of the studies of similarities between family correlations of physique compared to those of intelligence. He cited data showing that the average correlation between a single parent and a single child was about .55 and that the average mid-parent correlation with the mid-child was about .65.

To study family resemblances in verbal and numerical abilities, Carter (1932) used the Courtis Standard Tests of Arithmetic and the vocabulary section from the University of Minnesota College Aptitude tests. He tested 108 families with children over age 12 and converted their raw scores to standard scores by age. Scores for parents were determined separately by sex since there was a slight sex difference in the total arithmetic score.

For vocabulary, correlations ranged from .34 for mother-daughter to .07 for mother-son, and in arithmetic they ranged from .04 for father-daughter to .24 for mother-daughter. Carter summarized his results by noting that there was a pronounced tendency for the child in the family to resemble one parent more than another on these two traits. He obtained correlations of .54 and .64 for vocabulary and arithmetic, respectively, between the child and the more-alike parent and correlations of -.11 and -.28 with the unlike parent. He concluded that this was evidence that only a single gene controlled these traits.

Outhit (1933) gave the Army Alpha Intelligence Test to parents in 51 families and used the Stanford-Binet Intelligence Test for their children. The problem of equating the two tests was never completely worked out, so an arbitrary decision was made as to the age at which intelligence stops increasing in the adult. She found a mid-parent, mid-child correlation of .80, but this must be considered in light of the fact that the father-mother correlation coefficient was .74, which showed extreme selection in mating.

In a study involving adopted children as controls, Leahy (1935) gave the Stanford-Binet Intelligence Test and the Otis Intelligence Test to two groups of children and their parents. The children in the two groups were matched for school grade, age, sex, and father's occupation. She correlated the children's IQ's (corrected for unequal range) with the parents' scores on the Otis, with parents' scores on the vocabulary section of the Stanford-Binet, and with parents' level of education. Correlation coefficients for the adopted children ranged from .19 for the fathers' scores on the Otis test to .25 with the mothers' education, while those correlations for "own" children ranged from .51 for mothers' scores on the Otis to .47 for fathers' scores on the Stanford-Binet vocabulary.

Personality similarities among family members revealed by the Bernreuter Personality Inventory were investigated by Crook (1937). Family correlations for the Neuroticism, Dominance, and Self-Sufficiency scales were reported. In each case the lowest correlation was between father and son (near zero), while the highest reported was .57 between mother and daughter. The near-zero correlations between father and son might suggest sex-linked characteristics. Mother-father correlations ranged from -.05 to .06 showing no evidence of selective mating.

In England, the first large-scale correlational study between parents and children since Pearson's was done by Cattell and Willson in 1938. They used the Cattell Intelligence Scale and found the correlation between mid-parent and mid-child to be .78. In addition, they found the correlation of the children's (first born only) intelligence scores with the mothers' scores was .72, while with the fathers' scores it was .86. Cattell objected to the Jones and Outhit studies on the grounds that they had very homogeneous populations, but his own study appears to be biased by the high selectivity factor since the correlation between 101 fathers and mothers was .77. He did make corrections for age and for attenuation due to the unreliability of the test.

A replication of Jones' study (Conrad & Jones, 1940) yielded data very similar to that found by him in 1928. The findings of this second study of parent-child correlations were approximately the same; for example, using sigma scores of the Stanford-Binet Intelligence Test and the Army Alpha Intelligence Test, they found a correlation of .49 between parent and child compared to one of .53 for the same tests in the Jones study.

Skodak and Skeels (1949) reported in their longitudinal study of foster children that correlations between true mother's IQ and her own child's IQ increased with the child's age. At the initial testing the correlation was approximately zero, but at the fourth testing (done several years later) it had risen to .44. Foster mother-child correlations, however, remained about zero regardless of which testing session was selected.

Roff in 1950 nicely summarized a number of studies reporting correlations between parents' and children's scores on various personality tests. The results of these studies tend to agree with Crook's earlier studies (1937) with the exception they give somewhat higher correlation coefficients. Roff also reports a study done by Gjerde (1949) correlating parents' and children's interest patterns.

Using a modified version of Seashore's Tonal Memory Test, Woodburn (1954) compared mothers' scores on the test with those of their children. More than one child of the same family was included in the study. No correction for age had been made although age differences were reported. Using her raw data, a phi coefficient of .26 was calculated between mothers and their children. In addition, the data were fitted against a theoretical genetic model to test the hypothesis that the trait was due to a single autosomal gene with a 50% gene frequency. The fit with the model was moderately good, $p = .254$.

From their comparison of parent-child correlations of intelligence (.49) and height (.51) with those of grandparent-child correlations of intelligence (.34) and height (.32), Burt and Howard (1956) concluded that intelligence was inherited multifactorially.

Bayley (1954), stressing some similarities between physical growth and mental growth, showed that correlations between a child's mental score and the parents' education increased in magnitude from .03 at one year of age to .65 at age 17. This trend was also observed for weight and height but was less pronounced for boys than for girls.

Comparing Skodak and Skeels' results (1949) with correlations of children reared by their own parents, Honzik (1957) reported that the latter correlations ranged from .2 to .4, and increased steadily after age two. These correlations were based on various IQ tests given to the children compared to the number of years of education of the parents. Also, correlation coefficients computed between the children's IQ's and ratings of true mothers' intelligence ranged from .4 to .5 after the children were four years of age.

In summing up the above studies, several criticisms can be made. Almost all of these studies used some form of an intelligence test or ratings to demonstrate similarities between parents and their children. In some instances the ratings were rather oblique, as, for example, the number of years of parents' education; yet these ratings were compared with various IQ's tacitly assuming there would be high correlations between the two variables for a single individual. Occasionally, more than one type of intelligence test was administered for different ages and little attempt was made to show the intercorrelation between the tests.

Often several children in a family were compared to a single parent adding to the spuriousness of the coefficients reported (Burks & Kelley, 1928). In several studies, age differences were either ignored or incompletely partialed out. Few studies examined sex differences and only one tested the hypothesis that there might be other than an autosomal mode of inheritance. In fact, only two studies involved a discussion of genetic theory at all (Conrad & Jones, 1940; Woodburn, 1954). A few of the studies did use foster or adopted children as controls, however.

Very few of the investigations tried to measure simple traits. The exceptions were Cobb (1917), Mjoen (1925), Willoughby (1927), Carter (1932), and Woodburn (1954). Willoughby's study is the most complete and will be discussed in more detail later with the results of this study, but it is interesting to note that although his parent-child correlations averaged around .35, many of them varied widely from .1 to .5, with reliabilities ranging from .5 to .9. It would seem to lump all these subtests into one intelligence score could not but help to obfuscate the problem of heredity in mental traits.

In 1931 Conrad reviewed some studies of family correlations and concluded:

> "The total score in an entire intelligence test is almost certainly too complex for a comparison with eye color to be genetically significant. Most students of mental traits,...appear agreed on at least one point: that the total score on an intelligence test represents a composite (with unknown weights) of several more or less intellectual abilities, or traits...merging several tests in one spuriously increases the correlation between siblings or parents and child."

Jones, in commenting on the 1940 National Society for Studies in Education Yearbook devoted to studies of nature-nurture, stated in his opinion that:

> "The present volume is for the most part concerned with results based on total scores from standard generally accepted intelligence tests; little consideration is given to comparative studies of

> different types of test items or to analytic studies that attempt to deal with independent factors such as 'g,' 'V,' etc.
>
> "It seems probable, however, that fundamental nature-nurture inquiries will in the future include studies based on tests more homogeneous as to content than tests now in most common use." (Jones, 1940)

A further argument against using intelligence tests in genetic studies came from Blewett (1954). He tested twins using the Thurstone Primary Mental Abilities Tests and found no evidence for the heredity of an overall "g" factor of general intelligence. By 1958, Vandenberg, using factor analysis, demonstrated that the Primary Mental Abilities appeared to have separate genetic components.

In planning the present investigation of family similarities for evidence of genetic components, the above criticisms were borne in mind. First, tests were selected so that children and their parents could take the same tests. Second, several of the tests were selected which measured a single trait with the expectation that they might be relatively factor pure. Third, only one child of each sex within a specified age range from each family was included in the population. Fourth, age differences in raw scores were partialed out by transforming the raw scores for each age to standard scores, keeping the sexes separate. Significant sex differences were recorded. Fifth, the amount of selected mating was recorded, although no correction was made for this source of spuriousness. Sixth, the data were compared to several genetic models in hopes of generating new lines of investigation.

Chapter II

THEORY AND METHODOLOGY

Statement of the Problem

Most of the studies reported in Chapter I assumed that "intelligence" was passed from parent to child in the same manner as height, i.e., distributed continuously in an approximately normal curve, and that the child's height is usually intermediate between the parents' heights. On the other hand, the blood types of children are not intermediate between the parents, but usually favor one or the other, being segregated as discrete entities.

The early Mendelians maintained that all traits were inherited in a segregated manner, as one's blood type appears to be, while the followers of Galton championed the continuous mode of inheritance demonstrated by height, and built their statistical models to delineate their claims. Fisher (1921) resolved this apparent conflict between the two schools of thought by showing mathematically that the segregation theory of Mendel could also apply to Galton's continuous type of inheritance if one hypothesized that several genes were involved, each making a small contribution to that trait (Mather, 1949).

Theoretically, of course, even height might be capable of analysis into its discrete genetic components. An example might be the identification of the gene responsible for lengthening the femur a certain number of centimeters. But, since the genes influencing height appear to have cumulative effects which are highly correlated, it is not possible to demonstrate individual gene effects. Intelligence, on the other hand, has been found, from the application of factor analysis, to be composed of many traits (Bischof, 1954; Nunnally, 1959; Thurstone & Thurstone, 1941). It would seem more expeditious from a genetic standpoint to investigate the various traits that make up intelligence separately rather than study it as a cumulative score (Royce, 1957). Then, any hereditary components of these traits could be more easily identified.

It is generally acknowledged today (Stern, 1960) that there is no artificial division between a behavior pattern being "inherited" or being "acquired." Learning cannot take place in a vacuum, nor can heredity express itself without an environment. What we mean by a trait being "inherited" is that some of the observable variation can be attributed to inborn genetic factors and their interaction with the environment. Since acquired behavior might be defined as that in which some of the observable variation can be attributed to environmental factors interacting with the biological, it follows that the total behavior is the result of the interaction of heredity and environment. This interaction is not a summation of the effects of heredity and environment but probably can best be represented as the product of heredity and environment, ($H \times E = B$). For example, if there were only one allele of a gene antecedent to the behavior ($H = 1$), all the variation could be explained by the environment (let $E = 3$) and we would say that the three types of behavior were acquired or learned ($1 \times 3 = 3$). On the other hand, if there were two alleles (yielding three genotypes) for the gene antecedent to the behavior ($H = 3$), and if the environmental factor were 1, then $3 \times 1 = 3$, and all the variation in the behavior could be explained by the genetic make-up. It is probably extremely rare for the heredity factor or the environmental factor to be 1. Almost all behavior is going to represent variation in both factors with the resultant behavior both inherited and acquired!

In this study we will limit ourselves to investigating whether the variation in the selected behavioral traits has any palpable hereditary antecedents. It is generally believed (Fuller, 1954; Mather, 1949) that most characteristics are governed by polygenes and hence distributed continuously. Stern (1960) implies that almost all traits measured by mental tests are of the polygenic type, since their scores vary along a continuum. However, if a trait could be shown to depend upon a single genetic unit, it might show a discrete distribution, possibly a bimodal one. Therefore, tests should be selected not only to cover a wide spectrum of traits, but also to measure pure factors. Of course, results of tests with only a single factor loading do not usually yield a bimodal distribution, but this might be due to environmental forces, error variance, and contamination from other genetic influences, acting to mask the underlying dichotomy.

Actually, there is some evidence for believing that several traits are distributed dichotomously, especially in the sensory field. Deficiency in color perception is inherited as a sex-linked recessive trait (Stern, 1960), with approximately 5% of the scores of American males bunching in a small mode near the zero point of a distribution of scores on the American Optical Pseudo-Isochromatic plates (Thayer, 1947). The ability to taste phenyl thio-carbamide (PTC) has been shown to vary along a continuum of the logarithm of the concentration of the solution, but a histogram showing the number of people who first detect the bitter taste of PTC at each concentration indicates a very definite bimodality (Brandtzaig-Merton, 1958; Harris & Kalmus, 1949). Another test which shows a bimodal distribution of scores is a modification of the Kent-Rosanoff Word Association Test (Licht, 1947). More recently, the writer has obtained evidence suggesting that pitch discrimination, Koh's Block Design Test, the Primary Mental Abilities (PMA) Reasoning Test, and spelling ability may have an underlying dichotomy (Stafford, 1959).

Hypotheses to Be Tested

The present study makes the general hypothesis that some of the psychological traits, which have their scores distributed continuously, may actually have an underlying dichotomy which is blurred by various other effects.

More specifically, this study hypothesizes for each trait that:

(1) there is similarity between parents and their children unexplained by a resemblance between the parents;

(2) this similarity may be explained by hereditary components;

(3) these hereditary components are of the discrete or segregated type of inheritance.

Two methods will be used to test the above hypotheses. First, correlations will be obtained between family members to show intrafamily similarity and a possible fit to genetic models. Second, a new method developed for this study, "dichotomic analysis," will be used to test the possible goodness-of-fit to discrete genetic models. Since both the correlational method and the dichotomic analysis are predicated on certain genetic models, it seems appropriate to examine some genetic theory in detail. This will enable the reader to see how theoretical and actual calculations are derived to test the goodness-of-fit to these models.

Genetic Theory

There are several genetic models to which we could fit our data. It seemed paramount to select a theoretical model which was relatively simple and one which a large number of traits and characteristics fit. Two of the more common models of inheritance selected for this study are the simple autosomal dominant-recessive and the sex-linked dominant-recessive. In each model the simplest genetic conditions are posited: (1) there is complete penetrance, that is to say, whenever a dominant gene is present it will manifest itself; (2) there is no selective mating by the parents, at least in respect to the traits under investigation; and (3) there is no epistasis, which means there are no other genes at different loci masking the effects of the gene in the model. If these conditions are not met, then the results of the model fitting are questionable.

In the simple dominant-recessive autosomal model, we shall first assume that there are two allelic genes which we shall label "B" and "b" at a single locus on a chromosome. Since chromosomes come in pairs, four different combinations of the two genes are possible: BB, Bb, bB, and bb. It is impossible to differentiate between Bb and bB, so there are actually only three genotypes with twice as many individuals of the Bb type as there are of either the BB or the bb. If we also assume that gene B (which allows development of the trait) is dominant to gene b (which inhibits the development of the trait), then gene B will mask the effects of gene b. Individuals with either the combination of genes BB or Bb will manifest the trait equally and only those with the combination of bb will lack it. Thus, the three genotypes become only two phenotypes, BB + Bb, and bb. (Genotypes BB and bb are referred to as "homozygous" and the genotype Bb as "heterozygous.")

Since there are three genotypes possible, there are nine different possible combinations when parents mate as indicated in Figure 1. It can be seen by referring to Figure 1 that when a parent of type BB mates with

			MOTHER					
			bb	q^2	Bb	$2pq$	BB	p^2
FATHER	BB	p^2	Bb	p^2q^2	BB Bb	$2p^3q$	BB	p^4
	Bb	$2pq$	Bb bb	$2pq^3$	BB 2Bb bb	$4p^2q^2$	BB Bb	$2p^3q$
	bb	q^2	bb	q^4	Bb bb	$2pq^3$	Bb	p^2q^2

B = dominant gene, p = percent of dominant gene in population,
b = recessive gene, q = percent of recessive gene in population

FIG. 1. Probabilities of Various Genotypic Combinations of Parents and Resulting Types of Offspring

			CHILD	
PARENT	BB + Bb	$p^2 + 2pq$	$pq^3 + p^2q^2$	$pq^3 + 4p^2q^2 + 4p^3q + p^4$
	bb	q^2	$q^4 + pq^3$	$pq^3 + p^2q^2$
			bb q^2	Bb + BB $p^2 + 2pq$

FIG. 2. Expected Probabilities of Various Combinations of Parent and Chil
Phenotypes

another of type BB, all of their offspring will be alike and have the same BB combination of genes, and when a parent of type bb mates with another of type bb, all of their offspring will be alike and will also have the same combination of genes that their parents have. Similarly, when a parent of type BB mates with one of type bb, all of the offspring will be alike, that is type Bb, but they will have a different combination of genes than either of their parents. When parents that are heterozygous (type Bb) mate with other types, the resulting offspring are of different types. For example, when Bb mates with bb 50% of their offspring will be of the Bb type and 50% will be of the bb type. When a parent of type Bb mates with another Bb, three genotypes will result in the following percentages, 25% BB, 50% Bb, and 25% bb. Of course, when B is dominant over b only two phenotypes will be observed, 75% BB + Bb and 25% bb.

In addition to knowing the percentage of different types of offspring resulting from various combinations of parental matings, we also need to know the frequency of a particular gene in the population. If we discover that 64% of the population have a trait and 36% lack it, we can compute the frequency of the B and b genes in the population. We have assumed that there is only a B and a b gene at this particular locus, so we can let the percentage of B genes be "p" and the percentage of b genes be "q" where $p + q = 1$, and $0 < p < 1$. It is easier to calculate q than p because the probability of people lacking the trait (type bb) is q^2 while the probability of people having the trait is $p^2 + 2pq$. To find q we take the square root of the percent (.36) of people lacking the trait (type bb), and find the square root to be .60; so, by subtraction, p is .40.

We can now go back to Figure 1 and, knowing the frequency of the gene in the population, we can compute the probability of any particular parental mating combination. For example, using the hypothetical gene frequencies that we calculated above, we can determine how frequently a heterozygous father (type Bb) will mate with a heterozygous mother. We see that the probability of being type Bb is 2pq, so that the probability of both parents being type Bb is $4p^2q^2$. The chance of a type bb child resulting from this particular mating combination is 1/4. The percentage of bb children can be computed by showing the 1/4 of $4p^2q^2$ is p^2q^2 and substituting our hypothetical gene frequencies ($p = .40$, $q = .60$) we find that 5.8% of all children are of type bb and are born to parents who are both type Bb.

In this study we are specifically interested in the similarity between parents and their children. To determine how frequently we should expect a child to resemble one parent we must derive Figure 2 from Figure 1. Let us assume we are studying the resemblance of fathers and their sons. Fathers of the type BB + Bb have the trait and fathers of the type bb do not have the trait. We wish to know, given any gene frequency, how often we should expect their sons to be like them and how often we should expect their sons to be unlike them. Referring back to Figure 1 and looking across the row from Father bb, we see that whenever he mates with a mother who is also bb, all of their offspring will be bb and the probability of that mating is q^4. The first entry into the lower left-hand cell of Figure 2, where both father and son are recessive (lacking the trait), is q^4. There is still another source of sons who are recessive (type bb) from fathers who are also recessive. They come from a father of type bb mating with a heterozygous mother (type Bb). Since half of these children will be bb, and the probability of this mating is $2pq^3$, we add pq^3 to our lower left cell where both father and son lack the trait. To determine how many dominant sons (BB + Bb) there will be who have recessive fathers, we first enter the other half of the probability $2pq^3$ (father bb with mother Bb) and then add the entire probability of the mating between a father of type bb with a mother of type BB, which is p^2q^2. In a similar fashion, the frequency of recessive sons with a dominant father is obtained from the probability of the mating of a Bb father with a bb mother. This turns out to be pq^3 so this is entered into the upper left-hand cell of Figure 2. From the probability of the mating between a Bb father with a mother also of type Bb, which is $4p^2q^2$, we see that only 1/4 of the sons are recessive (type bb) so we enter p^2q^2 into the upper-left cell. This gives us exactly the same percentage in the upper-left cell that we found for the lower right. By subtraction we can calculate the frequency of dominant fathers with dominant sons to be $pq^3 + 4p^2q^2 + 4p^3q + p^4$ and we enter this into the upper right-hand cell of Figure 2. It should be kept in mind that since we are dealing with an autosomal model, the sex of the parent or child makes no difference. The same formulae could be used for mother and daughter or son. We have now shown that whenever we know the gene frequency of a dominant trait, we can compute the frequency of parents and their offspring being alike and unlike. This enables us to build quantifiable models to which we can fit our data.

Correlational Analysis

To express the similarity between family members in this study, correlation coefficients will be computed for each variable. If any of the correlation coefficients between father and mother prove to be statistically significant, it will indicate selective mating for that particular variable. Should selective mating (sometimes called assortative mating or homogamy) be found, it would distort the correlations between parents and their children. However, if it is adjudged that there is no selective mating, the correlations between parents and their children will be examined for possible significances. Any of these coefficients which show intrafamily similarity could be checked against theoretical coefficients obtained from a genetic model. This correlational method is unsatisfactory for providing evidence of genetic influences, especially in behavioral traits, since it is nearly impossible to separate the effects of environment from those of heredity. Contrary to this opinion, Conrad and Jones (1940) maintained that if mother-son and mother-daughter correlations are approximately equal to father-son and father-daughter correlations, it is evidence for a genetic influence on the trait. They reason that if environmental effects predominate, the mother-child coefficients should be higher than those of father-child because of her greater influence during the formative years. This would seem a hazardous conclusion since many activities occur in which the father might naturally be the mentor.

Fisher (1921) has presented formulae which, by making an assumption about the amount of dominance in the polygenes causing the trait, can estimate the amount of environmental influence operating when the correlations between siblings, parents and children, and mother and father are known. But this would also seem tenuous since there is no apparent way in which the amount of dominance can be estimated.

One possibility of using correlation coefficients to test the hypothesis of a genetic component occurs when there is a significant sex difference. If the difference between males and females in a particular trait is not due to cultural effects or demands, we can assume it has a physiological basis and a genetic origin. There are four genetic models which may be considered when sex differences are present: sex-linked, sex-limited, sex-influenced, and sex-modified (Zinkle, 1945). Sex-linked inheritance occurs on either the X or Y chromosome in males and on the X chromosomes in females, with no apparent crossing over between the X and Y in humans (Stern, 1960). If the gene should be on the Y chromosome, it would be found only in males. If the gene occurs on the X chromosome and if it were of the dominant-recessive type, some unique family correlations would result. An example of a sex-linked trait is hemophilia. Sex-limited inheritance occurring only in males is similar to sex-linked Y inheritance. However, it is transmitted on the autosomes instead of on the Y chromosome and is only manifested in the presence of one or the other sex hormones. Secondary sex characteristics are an example. Sex-influenced inheritance occurs when the genes are on the autosomes, but sex hormones act to alter the dominant-recessive relationship of the heterozygotes (type Bb) in such a way that while B would be dominant over b for males, it would be just reversed in females. One type of baldness is suspected of having this mode of inheritance. Sex-modified inheritance occurs when the gene is on the autosome but the frequency of manifestation of the trait is altered. For example, the metabolic abnormality resulting in the painful disease, gout, occurs in approximately 80% of the genotypic males, but in less than 12% of the genotypic females, even though it is considered to be dominant (Stern, 1960). It would probably be hardest to fit data to this latter model because the expression of the gene varies from trait to trait with fluctuating thresholds. A sex-limited model and a sex-linked Y model would be easily discernable and will be considered only if the data indicates a trait limited to one sex. The sex-influenced model has rarely been found in actual situations so no attempt will be made to fit data to it. However, innumerable characteristics have been found to fit the sex-linked X model so this model was finally chosen to be used when sex differences were apparent.

As was previously mentioned, transmission of a trait determined by a gene located on the X chromosome results in unique family correlations (Charles 1933; Hogben, 1932). The father passes his Y chromosome to his son while his X chromosome, which contains the gene determining the trait, is passed to his daughter. The son's X chromosome comes from his mother. Theoretically, then, we would expect a zero correlation between fathers and their sons with a significant correlation between fathers and their daughters. This latter correlation should be equal in magnitude to the one found between mothers and their sons. Mothers and their daughters would yield a somewhat smaller correlation.

Males who have an X and a Y chromosome will manifest a trait determined by a recessive gene more often than females who have two X chromosomes, since there is no possibility of a dominant gene on the Y. On the other hand, if the trait is determined by a dominant gene, then females will show the trait more often than males. Thus, the model will not only predict the relative magnitude of the various familial correlations but will also predict whether the trait is determined by a recessive or dominant gene.

Dichotomic Analysis

With the exception of the correlational methods used with the sex-linked genetic model, correlational techniques are generally ineffectual. They have yielded little evidence for either environmental or hereditary components of mental traits (Hogben, 1933). But besides their ineffectiveness in studying the interaction between heredity and environment, they can give little information about the possible mode of inheritance. Furthermore, since almost all correlational studies were predicated on an assumed continuous distribution of the trait, investigators have failed to realize that the same results might be obtained when the trait is discrete. Therefore, a new method has been devised for this study termed "dichotomic analysis."

If it could be shown that some of these mental traits have an underlying dichotomy, the trait could be tested rather easily for a possible genetic component by fitting it to a known genetic model. The fact is that, although traits may be transmitted by a single genetic unit, due to masking effects of other variables, they would be observed only as a continuous distribution instead of two separate groups. The method of dichotomic analysis is essentially an arbitrary quartering of a bivariate distribution of parent-child scores with a successive series of artificial divisions in the continuous distributions. The frequencies observed by these arbitrary quarterings may be compared to the theoretical expected genetic frequencies by a series of chi-square goodness-of-fit tests. Should a "good fit" be found at one of the artificial divisions in the bivariate distribution of father and son scores, and at approximately the same artificial division in the bivariate distribution of mother and daughter scores, then an underlying dichotomy would be assumed.

To demonstrate how the technique of dichotomic analysis works, let us take the hypothetical test scores of 50 fathers and their sons. We wish to know if the relationship of the sons' scores to the fathers' scores in any way fits that which we might find if the hypothetical trait has a basic hereditary component. The analysis is started by plotting the paired father-son score in a bivariate distribution with the father's score on the ordinate and the son's score on the abscissa of the graph shown in Figure 3. The assumption is made that the trait is a manifestation of an autosomal dominant-recessive gene and that a high score is dominant to a low score (it can be shown that when a low score is dominant to a high score the order of entries is simply reversed). For our first trial we will make the hypothesis that 90% of the population have the trait, that is to say, that they are phenotypically dominant, and that the 10% who lack the trait are recessive. Therefore, the bivariate distribution is first divided into quarters with a horizontal line at the 10th percentile of the fathers' scores and a vertical line at the 10th percentile of the sons' scores. This is shown in Figure 3 by the lines labelled "10th percentile." The expected frequencies can now be computed. The value of q is found by taking the square root of .10 (the 10th percentile must be changed into a decimal first), which equals .32, and, therefore, by subtraction, p equals .68. Substituting these values in our formulae for the four cells in Figure 2, the expected percentages are found to be 3.2% for the lower left-hand cell, 83.2% for the upper right-hand cell, and 6.8% for each of the other cells. Since the hypothetical population consisted of 50 fathers and their sons, the above percentages are multiplied by 50 to obtain the theoretical frequencies for each cell of Matrix A in Figure 4. These frequencies are

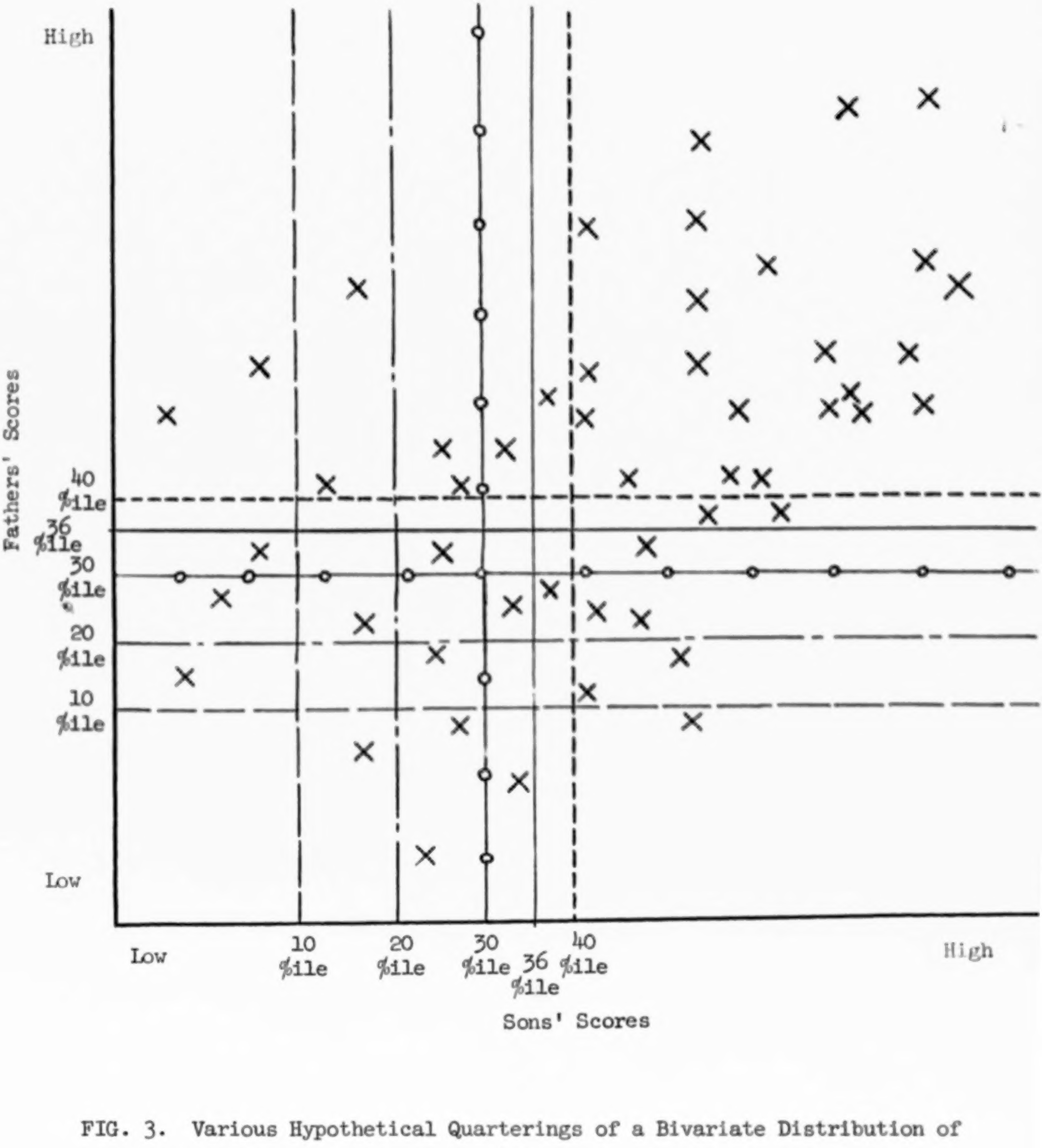

FIG. 3. Various Hypothetical Quarterings of a Bivariate Distribution of Father-Son Scores (Artificial Data)

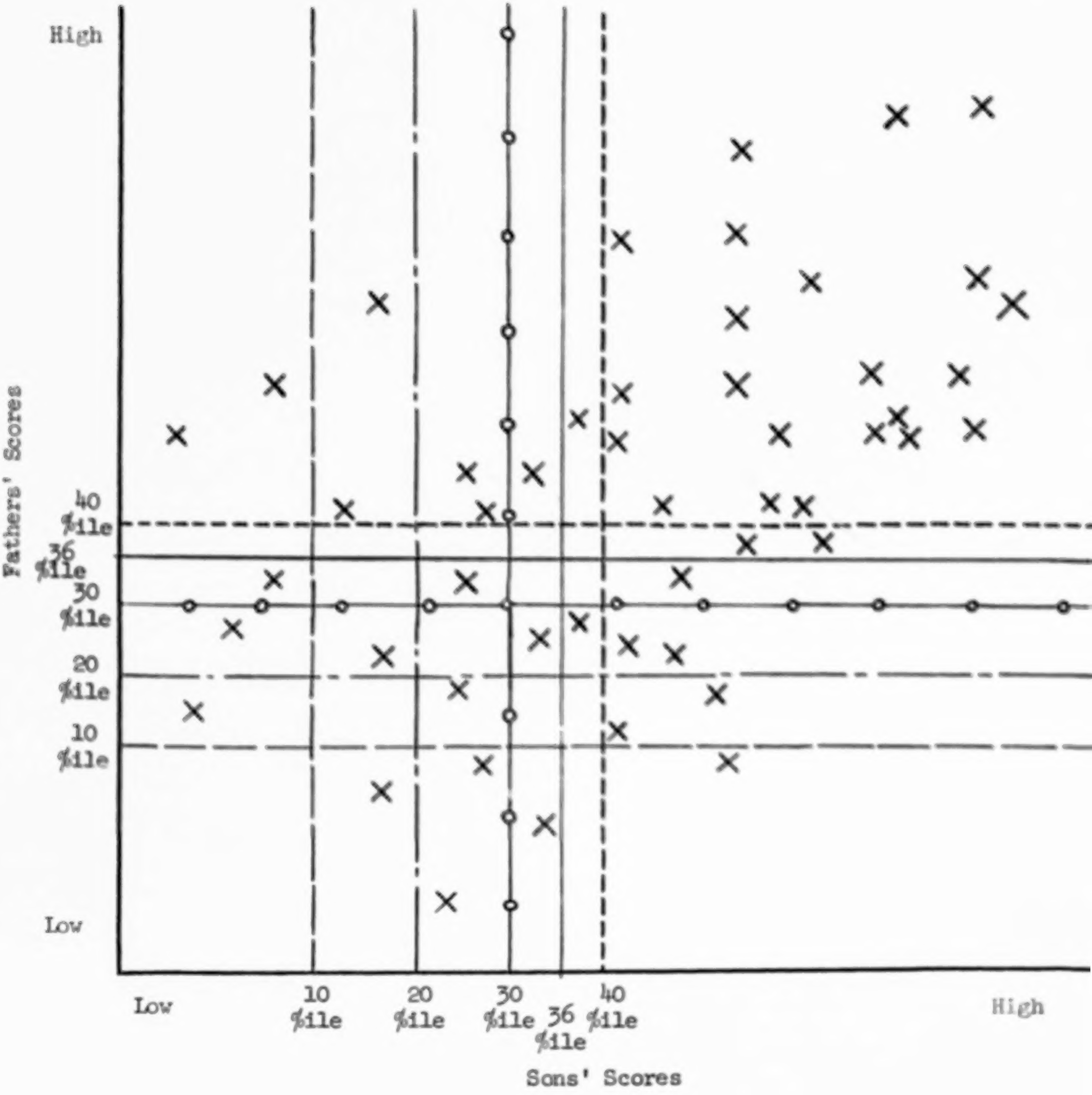

FIG. 3. Various Hypothetical Quarterings of a Bivariate Distribution of Father-Son Scores (Artificial Data)

placed on the middle line of each cell in Matrix A. Next, an actual count is made of the number of father-son plots in each cell of the quartered bivariate distribution in Figure 3, and these counts are entered in the top line of each cell of Matrix A of Figure 4. The difference between each theoretical frequency and the actual frequency is then squared and a chi-square is computed according to a standard formula (Siegel, 1956). The chi-square for Matrix A is 3.167. This is plotted in Figure 5 on the abscissa against 10% on the ordinate since the hypothesis was that 10% of the population was recessive.

The process is repeated by dividing the fathers' scores at the 20th percentile with another horizontal line and likewise dividing the sons' scores at the 20th percentile with another vertical line. The theoretical frequencies determined from the formulae in Figure 2 and the actual counts made of the father-son plots in Figure 3 are entered in Matrix B of Figure 4. The resulting chi-square of 1.202 is plotted in Figure 5 against the hypothesis that 20% of the population is recessive. This process is repeated for each successive decile. For clarity, some deciles have been omitted from Figure 3. The resulting graph, Figure 5, showed that the fits with the theoretical model were particularly good at the 30th and 40th percentile. Accordingly, it was determined that the closest fit possible occurred at the 36th percentile, where the resultant chi-square was only .016 and that the probability value associated with this chi-square (df = 1) was .90. With real data, the finding that approximately 36% of the people lack the trait would be cross-validated by following exactly the same procedure with the mother-daughter paired scores to see if the best fit of their scores was

Observed →
Theoretical →
Difference →

Matrix A ($q^2=.10$)

5 3.4 1.6	40 41.6 1.6
0 1.6 1.6	5 3.4 1.6

$X^2 = 3.167$

Matrix B ($q^2=.20$)

7 5.6 1.4	33 34.4 1.4
2 4.4 1.4	7 5.6 1.4

$X^2 = 1.202$

C ($q^2=.30$)

8 6.8 1.2	27 28.2 1.2
7 8.2 1.2	8 6.8 1.2

$X^2 = .650$

D ($q^2=.40$)

8 7.4 .6	22 22.6 .6
12 12.6 .6	8 7.4 .6

$X^2 = .142$

E ($q^2=.50$)

9 7.3 1.7	16 17.7 1.7
16 17.7 1.7	9 7.3 1.7

$X^2 = 1.118$

F ($q^2=.60$)

9 6.8 2.2	11 13.2 2.2
21 23.2 2.2	9 6.8 2.2

$X^2 = 1.999$

G ($q^2=.70$)

8 5.7 2.3	7 9.3 2.3
27 29.3 2.3	8 5.7 2.3

$X^2 = 2.606$

H ($q^2=.80$)

6 4.2 1.8	4 5.8 1.8
34 35.8 1.8	6 4.2 1.8

$X^2 = 2.192$

I ($q^2=.90$)

4 2.3 1.7	1 2.7 1.7
41 42.7 1.7	4 2.3 1.7

$X^2 = 3.651$

J ($q^2=.36$)

7 7.2 .2	25 24.8 .2
11 10.8 .2	7 7.2 .2

$X^2 = .016$

FIG. 4. ARTIFICIAL DATA. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (Low Score = Recessive)

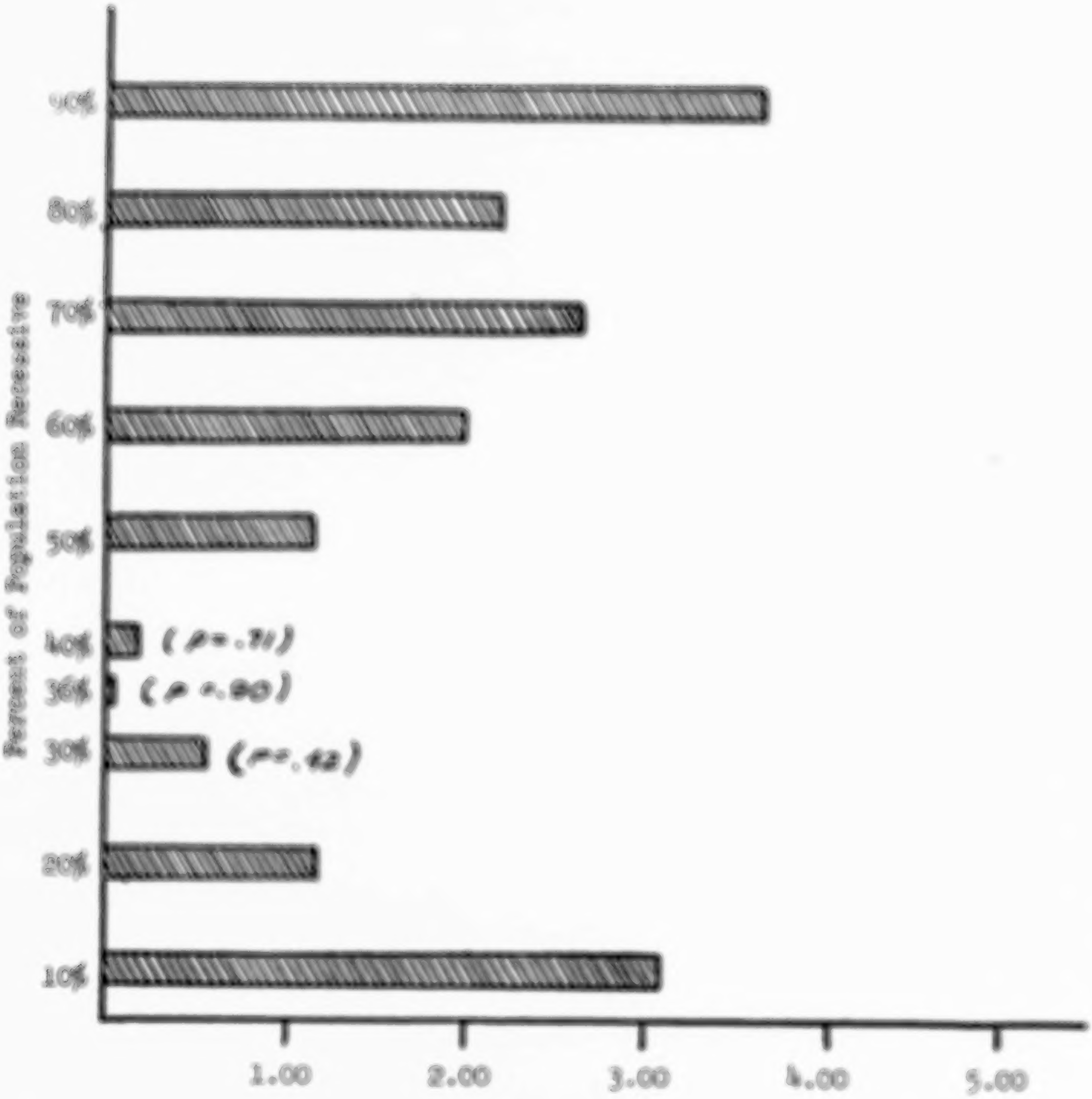

FIG. 5. Various Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (Artificial Data)

near the 36th percentile. If it were, it would be further evidence that there was a real underlying dichotomy for the continuous test score distribution of the variable.

The p values will be shown for the best fits between the data and the model, except when they may be spurious, due to the lowest theoretical frequency in a cell being less than five (Siegel, 1956). In these cases, they will not be used to make statements regarding the probability of a good fit or the lack of it.

The example given above demonstrated the technique of dichotomic analysis, but before this technique is applied to actual data, it is important to show that it can actually detect a bimodal distribution. To illustrate this, two bimodal distributions are set up with synthetic data, the first with the two modes two standard deviations apart, and the second with the two modes eight standard deviations apart (see top of Figure 6). It can be observed that in the distribution with the modes only two SD apart, the overlap is so great that the predicated bimodality is ostensibly a unimodal normal curve. When the modes are eight SD apart, however, the bimodality is clearly indicated. Using a matrix algebra solution[1], a bivariate distribution was simultaneously synthesized and tested by dichotomic analysis.

The resulting successive percentile cut-offs were plotted against the chi-squares obtained from the fitting of the synthesized data to the model (see Figure 6). The distribution with the modes two SD apart shows no

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[1] I am greatly indebted to Dr. Ledyard Tucker for the matrix algebra solution, and to Mr. David L. Brown for assistance in its application.

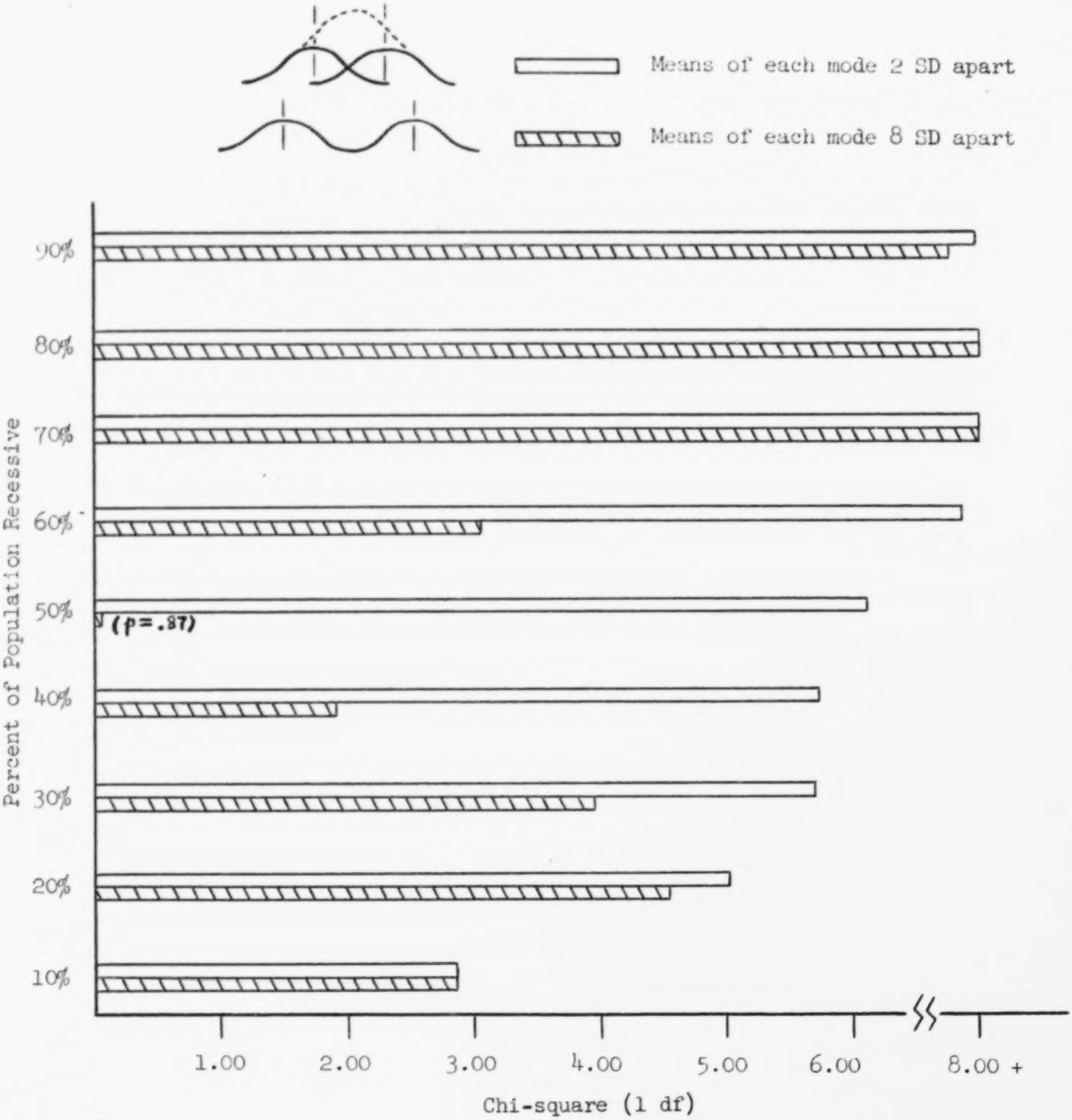

FIG. 6. Chi-square Goodness-of-fit Tests of Synthetic Data with and without Bimodality

evidence of bimodality, while the distribution with the modes eight SD apart clearly shows that the antimode exactly divided the total distribution into equal halves just as it had been synthesized. From this demonstration of the technique of dichotomic analysis, it may be concluded that it is possible to assess continuous data by this method and locate an underlying bimodality, at least under certain conditions.

It will be recalled that in addition to using an autosomal model, some of the data were fitted to a sex-linked model when significant sex differences were observed in the test scores. To use the technique of dichotomic analysis with a sex-linked genetic model requires some modifications. As we see from Figure 7, since males have only one X chromosome with the gene b manifesting the trait, the probability of having the trait is q. The probability, therefore, that a female has the trait is q^2, since she has two X chromosomes. If males average higher scores than females, a high score is assumed to be recessive and the successive artificial divisions of the bivariate distribution start with the high scores, since q is larger than q^2 when they are decimals. Figure 8 generated from Figure 7 shows that when fathers lack the trait, low score being dominant, all of their daughters will lack the trait because a father who is By can only pass his dominant gene B to his daughter. Whether the son has the trait or not depends entirely upon the mother since the son receives his X chromosome from her and his Y from his father. Similarly, when a low score is recessive, all the sons of a low-scoring mother will score low, since the mother passes her X chromosome on to her son and to be recessive she must be carrying a recessive gene on both of her X chromosomes. When the father has the trait

			MOTHER					
			bb	q^2	Bb	$2pq$	BB	p^2
FATHER	By	p	Bb by	pq^2	BB Bb By by	$2p^2q$	BB By	p^3
	by	q	bb by	q^3	Bb bb By by	$2pq^2$	Bb By	p^2q

B = dominant gene, p = percent of dominant genes in the population,
b = recessive gene, q = percent of recessive genes in the population,
y = inert Y chromosome in males

FIG. 7. Probabilities of Various Genotypic Combinations of Parents and Resulting Types of Offspring from a Sex-linked Model

			DAUGHTER		
FATHER	By	p	(0)	$p^3 + 2p^2q + pq^2$	
	by	q	$pq^2 + q^3$	$p^2q + pq^2$	SON
			bb q^2	BB + Bb $p^2 + 2pq$	
			MOTHER		

FIG. 8. Expected Probabilities of Various Combinations of Parent and Child Phenotypes from a Sex-linked Model

and it is dominant, all his daughters will receive this dominant gene from him and, hence, they will all have the trait.

In either case, whether the hypothesis is that the trait depends upon a recessive gene or upon a dominant gene, there is going to be a theoretical expected frequency of zero in one cell of either the father-daughter scattergram or the mother-son scattergram. To compute a chi-square with such a zero frequency is meaningless since dividing by zero equals infinity. However, by ignoring the cell with the zero expected frequency, the mathematical manipulations of computing chi-square may be performed and the resulting "pseudo" chi-squares reported. The graph of the pseudo chi-squares plotted against the percentile cut-offs in the scattergram of the female scores (male cut-off points would be the square root of these values) gives some idea of the relative closeness of fit. However, in no case should these pseudo chi-squares be interpreted with any statement of probability. It would seem obvious that if a good fit of the data to the model is not obtained when three cells of the matrix are summed for their chi-squares, it surely would be less of a good fit were it possible to add in the deviation from the zero cell. Hence, a Type 1 error is being made and the "true" fit could only result in a larger chi-square than the pseudo chi-square.

In conclusion, either correlational methods or dichotomic analysis may be used to fit actual data to the theoretical frequencies computed from either the dominant-recessive autosomal model or from the sex-linked model.

Chapter III

DESCRIPTION OF THE TEST BATTERY

Selection of Traits to Be Evaluated

There were several considerations involved in selecting the traits to be studied. It was desired that traits which showed sex differences be included, and also traits which previously had shown evidence of hereditary components. In addition, one or two traits which are known to be largely governed by genetic influences should be included for control.

Because traits which showed sex differences might be a clue to the genetic model, two traits which showed men averaging higher than women and two which showed men averaging lower than women were chosen. Another trait, English vocabulary, was chosen because current investigations give contradictory evidence for a genetic component. Two other traits known to be largely inherited were added for comparison. For the latter, it was necessary to rely upon physical traits since no common agreement has been reached concerning the relative genetic influence on mental traits. With the exception of English vocabulary, all of the traits had at least some evidence for hereditary components.

There were also practical considerations of the test selection in regard to the traits desired. Since the subjects were volunteers, there was a limit to the number of hours which they could reasonably be asked to give. This limit was arbitrarily set at two hours, so that all the tests had to be fitted into somewhat less time. In view of the size of the sample desired, and the necessity of completing the data collection within a reasonable length of time, it was obligatory to give the tests in groups; hence, only group tests, or tests adaptable to group administration, were chosen. Objective scoring methods were used for all tests to keep the investigatory bias to a minimum. Because parents were to take the same tests as their sons or daughters, the content of the tests was such that persons without much formal education, or those who had not had test materials of this type, would not be handicapped when compared to students presently in school. Finally, the tests must have a sufficient range of scores to give reliable measures and to cover the wide age span.

O'Connor (1928) concluded from the large individual differences, uncorrected by training, that clerical (perceptual) speed was inherited. Perceptual speed shows a definite sex difference, females averaging higher than males. Dolan (1959) suggests that this may mean it is a sex-linked dominant trait. However, he cautions that the available measuring instruments do not allow accurate determination of this hypothesis at the present time. It seemed wise to include the trait of perceptual speed in the study.

Since Crook (1937) and Roff (1950) found family relationships which suggested inherited components in several personality tests, it was planned to include some sort of a personality test. A word association test was chosen because (1) there is evidence that it measures some personality trait in an objective manner (O'Connor, 1948), (2) previous studies have shown that it yielded a bimodal curve (possibly indicative of a genetic component) (Licht, 1947), and (3) studies of siblings had shown frequencies suggesting a simple dominance (Franklin, 1945).

Quantitative reasoning was included because it shows a clear sex difference, males averaging higher than females, and also because Cobb (1917) found familial correlations indicating possible inheritance of some type of arithmetic reasoning as did Starch (1915).

Musical ability has often been suspected of being primarily inherited. Of all the traits thought to be indicative of musical ability, pitch discrimination seems to be more determined by heredity than any other (Mjoen, 1925). An analysis of twin data by the writer (Stafford, 1959) showed that scores of identical twins tended to cluster at the ends of the scoring scale. This was interpreted as an indication of an "all or none" trait. However, Kalmus (1949) failed to find any evidence that the ability to discriminate small differences in pitch is segregated in families. Guilford (1941) factored an intercorrelation of items on the Seashore Pitch Discrimination Test and found three factors: the first was a sort of overall attention factor, the second seemed to apply to difficult items, and the third to the easier items. These latter two factors might be analogous to the two clusters of scores found for identical twins. Another reason for choosing pitch discrimination is that, since the average person has not usually been taught pitch discrimination, the environmental component is held relatively constant.

A fifth trait which showed up as possibly being inherited from analyses of twin data was spelling ability (Stafford, 1959; Vandenberg, 1962). Earle (1903) and Starch (1915) had also indicated from their studies of siblings that there might be a hereditary factor in spelling ability. Sex differences in spelling ability, while not as large as in some other traits, seem to be consistent, with women averaging higher than men. Accordingly, spelling was introduced into the battery.

Inductive reasoning ability has also been suspected of having an inherited component. Thurstone's Primary Mental Abilities Test of reasoning was found to yield a distribution suggestive of bimodality from the analysis of the twin data (Stafford, 1959), and, in addition, both Blewett (1954) and Vandenberg (1958) found evidence that this test had a genetic component from their twin studies, although Strandskov (1955) failed to report any.

One of the largest sex differences observed in mental testing occurs in measuring the spatial visualization factor, where men average considerably higher than women. Calhoun (1945) suggested that this might mean the trait was inherited. Although an analysis of the PMA space test failed to show any clear evidence of a bimodal distribution, ratios between fraternal and identical twins' score differences did support the hypothesis that some hereditary influences existed (Blewett, 1954; Strandskov, 1955; Vandenberg, 1962).

It was desired to include one trait which does not appear to be controlled by heredity. The size of a person's vocabulary was chosen for this trait because previous studies have failed to give consistent evidence that vocabulary is influenced by genetic components (Blewett, 1954; Burks, 1928; Vandenberg, 1962), and also because several studies (Eels et al., 1951; Haggard, 1954) have called attention to the strong influences of cultural, i.e., socio-economic, determinants in vocabulary.

Construction or Modification of the Tests Selected

The next step was to choose tests to measure the traits which had been decided upon. Several tests were considered before selecting one to measure perceptual speed. A test was desired that would not require previous knowledge or be biased because of a person's occupation. The final decision was to construct a test similar to one used experimentally at the Human Engineering Laboratory (Barnum, 1941). This individually administered test was modified so that it could be given to a group, and was named the Symbol Comparison Test. Each item contained a pair of six symbol combinations with a line between them upon which the examinee was to mark an "S" if the two pairs of symbol combinations were the same, and an "X" if there was a difference between the two pairs; for example: #$%&)+ _____ #$%&)+. To reduce familiarity with numbers or letters, symbols from a typewriter were used. Differences were introduced by either substituting a new symbol for one of the original symbols or by interchanging positions of two symbols. The score was the number of items marked correctly out of a total of 100 items in the 5-minute period. Since this was essentially a speeded test, examinees were asked to mark their places at the end of the first 2 1/2 minutes to give equally timed split-halves in order to make an estimate of the reliability of the test.

The Mental Arithmetic Test was adapted from the Kit of Selected Tests for Reference Aptitude and Achievement Factors (French, 1954). It also had been part of one of the American Council on Education Psychological Examinations. The test was modified for this study by attempting to make it more of a mental task, thus reducing the loading on perceptual speed. A few new items were introduced and some of the answers and distractors were changed. Since the scoring of this test was to be done by hand, and answers were written on the test sheet itself, two extra distractors were added to each item to reduce the effect of guessing.

The Word Association Test was constructed by taking 100 words as stimuli. The examinees were asked to write down their first association to each word as it was read aloud (approximately 5 seconds between words). The test was scored by a method similar to that outlined by O'Connor (1934); see also Licht (1947). For each item, a tally was made for all responses to the stimulus word and the most common response noted. Then each person's test paper was scored on the number of most common responses given by him. By taking the number of most common responses as the total raw score, the papers were ranked from high to low and divided into quartiles. For each item, the number of times the most common response appeared in the top quartile was tallied and likewise the number of times the most common response appeared in the bottom quartile was tallied. A ratio was then computed for each item by dividing the frequency of the most common response in the top quartile by the frequency of the most common response in the bottom quartile. Those items which had a ratio of 2.00, or higher, were used to rescore the papers to obtain a new raw score. Again the papers were ranked and the top and bottom quartiles were selected to compute new ratios between the frequency of the most common responses in the top quartile and those in the bottom quartile. This time other common responses besides the most common responses were examined for their top/bottom quartile ratio and, if these also had ratios exceeding 2.00, they were included with the most common responses. The iteration was stopped when there was no appreciable increase in the average top/bottom ratio. All responses now used for scoring were classified as "objective significant responses." In a similar manner, for each item, the frequency of the responses in the bottom quarter were divided by those in the top quarter and any of these responses whose ratios were over 2.00 were classified as "subjective significant responses." In the final scoring these significant subjective responses were subtracted from the objective significant responses and a constant added so that the final score would be positive.

The Pitch Discrimination Test was constructed similar to the one designed by Seashore (Saetveit, Lewis, & Seashore, 1940). Seashore's test consisted of listening to a pair of notes and determining whether the second note was higher or lower than the first note. The design of the present test contains two modifications. The first is the inclusion of items in which the first and second note are the same. This reduces the number of items on which an examinee might guess correctly. The second modification is to present the first note always at the same number of cycles. Seashore's test did not have a constant pitch for the initial note but varied the number of cycles of the first note depending upon whether the item was to be higher or lower.

The present test was constructed[2] by taping notes from an audio oscillator. The initial note is always constant at 400 cycles and is followed by a note either higher or lower in pitch or of the same frequency. Intervals between the notes of each pair ranged from 30 cycles to 2 cycles apart. The examinee was instructed to mark his answers "H" when the second note sounded higher, "L" when the second note sounded lower, and "S" when the second note sounded the same as the first. The raw score was the total number of pairs correctly answered out of a total of 60 items.

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[2] Mr. Joseph J. Bernier collaborated in the design of the test, Mr. William Taylor constructed the audio oscillator, and Dr. Jack Vernon aided in the technical standardization.

Words for the Spelling Test were taken from several sources. Efforts were made to find words which ranged in spelling difficulty and would reflect the actual ability of good and poor spellers. Foley (1956) found that people tended to have more difficulty spelling words of which they did not know the meaning. Consequently, the words selected were checked against the lists of Diederich and Palmer (1956). It was hoped that by eliminating words difficult in meaning, the correlation between spelling and vocabulary would be reduced. Thirty words in all were chosen, the easiest to spell being "care," and the most difficult "silhouette." The words were read slowly and the examinees were asked to print their answers. Raw score was the total number of words spelled correctly.

The Letter Concepts Test was chosen to measure inductive reasoning. It had been originally designed to measure inductive reasoning and was similar to Thurstone's test called "Letter Grouping" (French, 1954). Each item of the Letter Concepts Test consisted of two pairs of letter groups related by some rule and a third letter group to be paired with one of five alternative letter groups. The problem for the examinee was to find the rule which related the two pairs and then apply the rule to the third letter group in order to choose the appropriate matching letter group from the five alternatives. Although this test may have a loading on deductive reasoning as well, it seemed to be nonverbal and had a lower correlation with perceptual speed than Thurstone's Letter Grouping Test. Raw score was the correct number of items.

In order to measure the spatial visualization factor, the Identical Blocks Test of Educational Testing Service was selected because the items gave a wide range of difficulty, the test scores showed clear sex differences, and, by intuition, did not appear to load on other factors. Twenty-five items were originally selected from a former section of a College Entrance Examination Board test by choosing those with difficulty levels easier than 50% and with relatively good biserial coefficients. Seven items had to be discarded because they were in current usage by the Navy Department. Two minor modifications were made in the original items to give a greater simulation of depth, first, shading was put on the blocks, and second, lines which did not actually meet were left a short distance apart. Raw score was the number of items correctly answered.

The English Vocabulary Test selected for this study had been originally designed to estimate the number of words a person knew. Words were sampled from a dictionary, along with misleads for each item, and the examinee was instructed to circle the correct word if he knew it, or to circle the question mark placed to the far right if the word was not known to him. The test used in this study was a short form of the original test (Stafford, 1961) given to a group of high school juniors. The results of an item analysis on these juniors were used to select 42 words, which were placed in an approximate order of difficulty, for the short form. No time limit was given and the number of words answered correctly was the raw score.

A questionnaire was given to the parents and children immediately preceding their testing. Heights and weights were obtained from this questionnaire as well as information regarding the amount of schooling and occupations of the parents. The latter information provided an estimate of the amount of selectiveness and bias in the sample.

The eight mental tests and the two physical self-reports that made up the variables under investigation in this study are summarized in Table 1. Details of their administration and sample items are listed in Appendix C.

TABLE 1

Variables Under Investigation in the Order of Their Administration

	Number of Items	Time in Minutes	Method
Questionnaire (height, weight, etc.)	--	5[a]	self-report
Symbol Comparison Test	100	5	paper and pencil
Word Association Test	100	9[a]	dictation
Mental Arithmetic Test	20	9	paper and pencil
Pitch Discrimination Test	60	7[a]	tape recorder
Letter Concepts Test	14	8	paper and pencil
Spelling Test	30	6[a]	dictation
Identical Blocks Test	18	8	paper and pencil
English Vocabulary Test	42	15[a]	paper and pencil

[a] These tests did not require exact times; all other tests were exactly timed.

Chapter IV

PROCEDURES

Description of the Population

It seemed desirable to have as broad a selection of subjects as possible, but, since reliance was being placed upon volunteers, it is very likely that the sample was biased.

Subjects were usually obtained in the following manner. A junior or senior high school superintendent and principal were contacted and they, in turn, would refer the matter to the guidance counselor. The guidance counselor arranged to have an announcement (see Appendix B) sent home by the students explaining the project and specifying age limits (students must have had their thirteenth birthday, but not their eighteenth). A return slip was provided at the bottom of the announcement for those interested in participating. Volunteer families checked off the times preferred, listed their names and telephone numbers, and returned their slips to the guidance counselor. He would turn them over to the investigator who made appointments, by telephone, to test the families. In some instances, approval for the study was initially sought through the PTA or Board of Education.

The original plan was to have exactly 50 families with sons and 50 families with daughters. It soon became clear that many more families with daughters were volunteering than those with sons. Also, several of the families asked to have more than one of their children tested; this occasionally included both a boy and a girl within the age limits. Therefore, in the final group there were 104 families with 58 sons and 72 daughters. All families were Caucasian as far as could be observed, and upper-lower to upper-middle class in socio-economic status, as judged by their education and occupations.

Among the schools cooperating in this study were one city junior high school, one high school located in a college town, two joint junior-senior high schools, one suburban junior-senior high school, and one small-town high school. (The names of these schools and their officials at the time of testing are listed in Appendix A.) No attempt was made to sample proportionately from these different kinds of schools; it was only desired to have representative schools. The percentage of volunteers was very small; the number of families who volunteered ranged from 5% to 10% of all those queried.

Although there was a wide range of occupations represented for the fathers, it was not proportionate to the percentage of the population engaged in these occupations. In years of education, there was a skewed distribution towards higher education; this is probably explained by having mentioned in the appeal that research was necessary in this area of genetics. Once again, however, there was a wide range of the number of years of education. This demonstrates that while the sample was not highly homogeneous, it was somewhat biased.

It had been decided before the start of testing that if any irregularity was noted by both the test administrator and the proctor the case would be dropped. Two of the subjects were excluded because of such incidents. One was a student who refused to comply with directions and took the tests with no apparent attempt to answer correctly, finishing long before anyone else. Both the test administrator and the proctor noted this incident and, therefore, this case was dropped. The other incident involved a student who openly and compulsively cheated. Again, both the administrator and the proctor noted it and this case was also dropped. In the first case mentioned, another sibling in the family being tested took the tests in a normal fashion, so the family was retained with that sibling. In the second case, since this was the only child in the family taking the test, the parents were retained only in the larger population to compute means and standard deviations, but the child was dropped from all calculations.

After the means and standard deviations had been computed for each age group and for both sexes, stepparents and adopted children were removed before the family computations. There were four families in which there were stepparents: one daughter with a stepmother; two daughters with stepfathers; and one son with a stepmother. These sons and daughters were only retained for calculations with their true parent. One child was adopted and was excluded from the family calculations. In families where more than one daughter or more than one son had been tested, only the oldest child was used in the family calculations. The final population in the family calculations was fathers-sons = 51, fathers-daughters = 62, mothers-sons = 50, mothers-daughters = 63, and fathers-mothers = 99.

Testing Procedures

All tests were administered by the investigator, usually with the aid of a proctor. Tests were given evenings between 8:00 and 10:00 p.m., or between 10:00 a.m. and 12:00 noon on Saturday. The school at which the testing was being done generally provided the room, but several of the groups in the vicinity of Princeton were tested in the laboratory of Educational Testing Service.

The tests and questionnaires were marked with a serial number for each family and were put into an envelope marked the same way. The family serial number was followed by a "-1" for father, "-2" for mother, "-3" for the oldest son, "-4" for the oldest daughter, "-5" for the next to oldest son, "-6" for the next to oldest daughter, etc. Upon the arrival of a family, the envelopes were handed to the father with instructions to hand them out according to the above-mentioned codes. During the first 5 to 10 minutes, time was taken to reassure the examinees that the tests they were about to take were not intelligence tests, but were experimental aptitude tests. Five minutes was then allowed for filling in the questionnaire; latecomers and those who required more time were told to complete the questionnaire at the close of the testing period. The order of the tests, number of items, and time limits have been given in Table 1. As each test was completed, the subjects were asked to return it to the envelope, thus simplifying directions and assuring that the allotted time was adhered to. A short explanation of the tests and the purpose of the study followed the testing period prior to dismissal.

Procedure for the Analysis of Data

After the data were collected, all envelopes were checked to determine that the correct family code number and family member number had been placed on each test paper. The papers were then sorted according to the particular test, and the questionnaires with names and other identifying or personal data were removed. All tests were scored and rescored, with a third check made by scoring odd and even number of items in preparation for computing reliabilities.

On a separate graph for each sex, raw scores were plotted for each age. For the adults, two consecutive ages were combined into one age group because of the small number of cases at certain ages. Each graph was then inspected for age differences by plotting the means of the scores for each age group and drawing a smooth curve that best fitted these means. The means of males and females were then averaged, replotted, and smoothed. However, the standard deviations were determined on combined males and females after which they were also plotted and smoothed. Linear derived standard scores were then computed for all raw scores, according to the formula below (Gulliksen, 1950):

$$v_i = \frac{S_v}{S_x} X_i + M_v - \frac{S_v}{S_x} M_x$$

where:

v_i is the linear derived standard score,

M_v is the desired mean of the standard scores (set at 500),

S_v is the desired standard deviation of the standard scores (set at 200),

X_i is the raw score to be transformed,

M_x is the mean raw score from the smoothed curve,

S_x is the standard deviation raw score from the smoothed curve.

The standard scores were computed from a program written for the augmented IBM-650 computer[3] and the output was coded so that it could go directly into the program for correlational analysis (Lotto, n.d.).

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[3] The writer is indebted to Mrs. Anna Wink, of the Computation Center, Pennsylvania State University, for assistance in the writing of this program.

Correlations between family members for each variable were computed as were intercorrelations of all variables for each family member. Since the N varied with the family dyad, N's for the intercorrelations also varied.

The reliabilities were computed for each variable by family member. The possibility of sex differences was evaluated by means of the sign test for the 15 age groups.

Dichotomic analysis was carried out for all variables, pairing father-son, mother-daughter for those variables not showing sex differences and pairing father-daughter, mother-son for those variables showing sex differences.

The goodness-of-fit of the dichotomic analyses were estimated by chi-squares. These chi-square values were then plotted against the percentiles used in the trial quarterings of the scatterplots. When appropriate, p values were also listed.

The results of all these calculations are given in Chapter V.

Chapter V

RESULTS AND DISCUSSION OF THE ANALYSIS

Analysis of the Tests

The means and standard deviations of each variable for fathers, mothers, sons, and daughters are reported in Table 2. These statistics are based upon the same population from which the standard scores were derived. It can be seen in Table 2 that the differences between males and females are rather large for some variables, but for others, even when the differences are consistent for both parents and children, they are smaller. Some of the mothers were younger than any of the fathers, so it was decided to test for sex differences by comparing only those age groups where both the males and females had at least three members. As was mentioned in the section on Procedure for the Analysis of Data in Chapter IV, for certain adult ages containing relatively few cases, two successive ages were lumped together to form a single age group. This resulted in 10 adult age groups. For the offspring, each of the five ages, 13 through 17, formed an age group. In all, then, there were 15 age groups where males could legitimately be compared to females.

Table 3 gives the results of applying the sign test to the direction of the sex differences for these 15 age groups. The p values are two-tailed (Siegel, 1956) because in only two of the mental tests could the direction of the sex difference be predicted. Three of the mental measures were judged to have significant sex differences, the Mental Arithmetic Test and the Identical Blocks Test, on which males averaged higher than females, and the Spelling Test, on which females averaged higher than males. The chances that these differences were due to sampling error are less than 1 in 100.

TABLE 2

Means and Standard Deviations of Ten Variables for Fathers, Mothers, Sons, and Daughters

Variable	Fathers (N=104)		Mothers (N=104)		Sons (N=58)		Daughters (N=69)	
	M	SD	M	SD	M	SD	M	SD
Symbol Comparison Test	62.8	12.0	65.0	12.5	63.4	10.0	69.9	10.1
Word Association Test	22.6	9.9	23.1	8.1	22.0	9.7	24.0	9.2
Mental Arithmetic Test	9.7	3.8	5.9	3.6	7.7	4.0	6.3	3.0
Pitch Discrimination Test	50.3	8.2	46.4	8.5	50.5	8.1	50.2	7.5
Letter Concepts Test	5.2	2.5	4.1	2.7	7.5	2.6	7.5	2.2
Spelling Test	18.9	5.8	20.0	4.7	15.2	5.0	17.0	4.7
Identical Blocks Test	10.2	4.0	6.3	3.2	11.8	4.1	9.6	3.8
English Vocabulary Test	29.8	4.9	27.9	5.3	22.1	4.6	22.7	5.0
Height	69.9	2.7	64.0	2.5	67.6	3.9	64.3	2.3
Weight	172.5	18.8	133.4	19.0	138.3	25.8	117.1	13.3

TABLE 3

Sex Differences Determined by the Sign Test for All Family Members

Variable	Total Age Groups	Male Groups Averaging Higher	Female Groups Averaging Higher	Two-Tail p values
Symbol Comparison Test	15	5	10	.302
Word Association Test	15	3	12	.036
Mental Arithmetic Test	15	13	2	.008*
Pitch Discrimination Test	15	11	4	.118
Letter Concepts Test	15	12	3	.036
Spelling Test	15	1	14	.002*
Identical Blocks Test	15	14	1	.002*
English Vocabulary Test	15	10	5	.302
Height	15	14	1	.002*
Weight	15	14	1	.002*

*Significance level set at .01.

To test these three variables by dichotomic analysis, they were fitted against the sex-linked model instead of the autosomal model. Height and weight were also fitted against the sex-linked model since they showed significant sex differences too.

Reliabilities for the mental tests are given in Table 4. It should be noted that the size of the sample utilized to compute these coefficients varied slightly from test to test. This is due to the fact that some test papers, although scorable for the total test score, could not be used for estimating the reliability. For example, in the Symbol Comparison Test the examinees were asked to mark the time on their test booklets at a given signal so as to give two equally-timed sections from which a split-half reliability could be computed. However, in one testing session the examiner neglected to call time at the half-way point, hence these papers could not be used to compute the reliability although the total score was not affected. In other tests, for various reasons, it was decided to exclude a particular test paper from the computations. As an illustration of this, one boy did not complete the English Vocabulary Test because he did not see the items on the last page. His total score was estimated by comparing his score on the first page with the other boys who had the same first page total and taking their average total score as his total score. Obviously, his paper could not be used to obtain a reliability coefficient.

In general, however, the reliabilities are probably fairly good estimates, since only the Symbol Comparison Test was highly speeded and, as was previously mentioned, this correlation coefficient represents two equally-timed halves augmented by the Spearman-Brown formula (Gulliksen, 1950). All the other coefficients were also corrected for length with this formula.

TABLE 4

Reliabilities of Each Test by Family Member

	Fathers		Mothers		Sons		Daughters	
	N	r	N	r	N	r	N	r
Symbol Comparison Test	97	.89	96	.90	55	.78	65	.85
Word Association Test	104	.89	104	.74	58	.89	70	.89
Mental Arithmetic Test	104	.87	104	.86	58	.80	70	.81
Pitch Discrimination Test	103	.91	104	.91	57	.92	69	.92
Letter Concepts Test	104	.69	104	.72	58	.68	70	.46
Spelling Test	104	.89	104	.84	58	.80	70	.82
Identical Blocks Test	104	.87	104	.74	58	.86	70	.84
English Vocabulary Test	104	.84	104	.87	57	.83	70	.78

The Letter Concepts Test appeared to be speeded for females although no sex difference was found. In most of the tests, a large majority of the examinees finished in the allotted time. Considering the fact that these tests were relatively short, the reliabilities appear to be satisfactorily high for all the tests except the Letter Concepts Test.

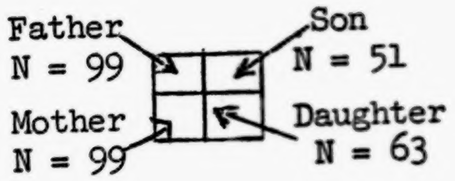
Since it was stipulated in Chapter II that tests measuring simple traits were desired, the intercorrelations of all the variables should be examined to see how independent these tests actually are of each other. In Table 5, four correlation coefficients are given for the correlation of each variable with every other variable. In each case, the upper left-hand coefficient is for the fathers' test scores, the lower left-hand coefficient is for the mothers' test scores, the upper right-hand one for the sons' scores while the lower right-hand one is for the daughters' scores. The population sample used for these intercorrelations is somewhat smaller than that given in Table 2, since this is computed upon the reduced population from which stepfathers, stepmothers, adopted children, and younger brothers and sisters were excluded.

One other factor, common to the mothers, apparently entered some of the scores. It may be observed in Table 5 that their intercorrelations were generally higher than those of any other family member. Referring back to Table 2, it can be seen that the average score of the mothers is lower than would be expected by comparing it to the average scores of the fathers and daughters. This general depression of their scores could come about because they had been out of the competitive world, or it could be a general function of an interaction between sex and age. There seemed to be in many of the women the attitude that they could not do as well as their husbands

TABLE 5

Intercorrelations for Ten Variables for Each Family Member

	2	3	4	5	6	7	8	9	10
1. Symbol Comparison Test	-11 -08 03 13	17 12 48 18	01 02 22 22	26 10 48 13	16 07 46 19	-02 -04 53 00	13 23 38 16	-05 03 12 07	-15 15 -05 -03
2. Word Association Test		21 12 01 01	01 -03 -02 04	06 -01 -04 09	07 -25 -12 -04	14 10 00 21	03 -15 -06 02	02 -02 -03 06	-01 00 04 -08
3. Mental Arithmetic Test			08 16 25 28	53 62 55 41	46 54 53 29	31 28 51 35	44 35 46 31	20 -07 03 14	08 -05 -09 17
4. Pitch Discrimination Test				-12 12 28 23	28 18 20 26	04 21 15 06	18 26 32 18	17 06 -01 12	09 24 -01 11
5. Letter Concepts Test					36 40 43 15	24 56 48 27	30 20 36 26	21 -12 02 13	01 -08 -10 11
6. Spelling Test						05 13 44 13	68 45 55 50	21 14 14 04	-07 03 -17 16
7. Identical Blocks Test							18 21 40 30	06 -22 01 25	-04 -08 -11 20
8. English Vocabulary Test								24 04 09 15	-15 22 -10 -05
9. Height									46 66 34 54
10. Weight									



or children because they had been merely housewives and mothers. A number of them expressed their feelings by jokingly saying, "I'm no good at things like this," or "Now, you'll find out how dumb I am." It may be that some of them felt at a disadvantage, being out-of-touch with the competitive worlds of school and business. It would be interesting to find out if this attitude characterizes both women who work in the outer world and those whose principal occupation is mother and homemaker. At any rate, the general depression of mothers' scores no doubt had some interfering action on the study.

As Table 5 shows, the Word Association Test has the lowest correlations with other variables in the battery. The Symbol Comparison Test and the Pitch Discrimination Test also have fairly low correlations with the other variables. On the other hand, the Spelling, Mental Arithmetic, and English Vocabulary Tests have some of the highest intercorrelations among themselves, as well as high correlations with other variables, and this seemed to hold for all family members. Another relatively high correlation is between the Mental Arithmetic Test and the Letter Concepts Test. Weight and height are closely correlated, as would be expected, but otherwise they show low positive or slightly negative correlations with the mental test scores, indicating that they are independent of the mental traits. We conclude that most of the measures selected were relatively independent of each other.

Correlational Analysis

It should be recalled that the first hypothesis stated that there is a similarity between parents and their children unexplained by a similarity between the parents. Therefore, let us examine the father-mother correlations first, for if the parents' test scores show a high degree of similarity, it might be an explanation of the similarity between them and their children. Looking at the first column in Table 6, there are only two variables in which the fathers' and mothers' scores correlate significantly, the English Vocabulary Test and height ($p = .01$). The correlations between fathers and mothers for the Spelling Test scores and weight are not significant even at the .05 level.

Assortative mating or homogamy, as it is sometimes called, can seriously affect an investigation of similarities between parents and their children. Lush (1945) states that the parent-child correlations approach a limit determined by the correlation between the parents and the number of genes involved in the trait. In other words, if there had been a selection factor so that the parents chose similar mates in respect to the particular trait, the positive correlation for this trait between parents and their offspring would have been spuriously inflated, providing it had been based on hereditary factors (Wright, 1921a; 1921b).

Jones (1929) and Richardson (1939) have reviewed studies purporting to show the amount of homogamy between parents. In addition to the problem of homogamy, Price (1936) and Bartlett (1937) have rasied the possibility of cross-homogamy as one cause of intercorrelations between variables. An example of cross-homogamy would be males who are high in reasoning ability marrying females who are high in clerical ability. This would result in a correlation between the reasoning and clerical abilities for later generations.

To check for cross-homogamy in the present study, the 90 correlations between fathers and mothers on all variables were checked for significance.

TABLE 6

Correlations Between Family Members for Each Variable

	Father-Mother	Father-Son	Father-Daughter	Mother-Son	Mother-Daughter
N=	99	51	62	50	63
Symbol Comparison Test	-.05	.27*	.21	.14	.14
Word Association Test	.08	.08	.08	-.04	.05
Mental Arithmetic Test	.06	.07	.18	.51**	.21
Pitch Discrimination Test	.03	.36**	.31*	.22	.25*
Letter Concepts Test	.03	.15	-.07	.32*	.33**
Spelling Test	.12	.45**	.06	.25	.28*
Identical Blocks Test	.04	-.03	.30*	.33*	.17
English Vocabulary Test	.31**	.32*	.10	.46**	.16
Height	.25**	.14	.49**	.62**	.37**
Weight	.12	.34*	.13	.46**	.22

*Less than the .05 level of confidence.

**Less than the .01 level of confidence.

Four correlation coefficients were found at the .05 level and two at the .01. This is about what would be expected by chance. Therefore, it is concluded that there are no cross-homogamous effects in the present study.

One question which might be important to answer is, "Are these parents any different from parents in general?" Since there is no population from which a check could be made, we must turn to parents' scores from other studies. Two studies which might supply data to answer the above question are Willoughby's (1927) and Foley's (1954) since they contained a few variables which might be classified as similar to variables used in the present study.

The first variable which will be compared between the present study and the other two studies is that of knowledge. A correlation coefficient of .31 was found between fathers' and mothers' scores on the English Vocabulary Test in the present study. This compares very closely with a coefficient of .34 found between fathers' and mothers' scores on an antonym and synonym test by Willoughby, and is exactly the same as that found by Foley between husbands and wives (.31) on an English vocabulary test.

However, the correlation between fathers and mothers on the Letter Concepts Test of inductive reasoning was .03, which is very low compared to either the correlation coefficient of .17 between fathers and mothers on Willoughby's Number Series Completion Test, or the coefficient of .21 found by Foley between husbands and wives for a test of inductive reasoning.

The correlation between parents' scores on the test of spatial visualization used in the present study, the Identical Blocks Test, was .04, while Willoughby's Geometric Forms Test had a correlation of .25 between parents, and Foley's correlation between husband and wife on the Wiggly Block Test of visualization was .14.

We might check one other variable. Pearson and Lee (1903) gave the following correlations between parents and their children for height: Fa-Son, .514; Mo-Son, .494; Fa-Dau, .510; Mo-Dau, .507. The present family correlations for height given in Table 6 are not too discrepant from Pearson and Lee's with the exception of the Fa-Son correlation. Especially close is the correlation of .28 between the fathers and mothers for height, found by Pearson and Lee, compared to the present finding of .25.

We may conclude that, in comparison, the correlations in the present study between fathers and mothers are as low or lower than those found in other studies. This indicates that the parents are probably not more selectively mated than parents in general.

The next step in checking the first hypothesis is to examine the correlations between parents and their offspring. In Table 6, it can be seen that only the correlations of the Word Association Test fail to have at least one significant at the .05 level. This casts doubt on the possibility that hereditary components are operating for this variable. This finding is, of course, in direct contrast to the conclusion of Franklin's (1945), who found evidence from siblings' test scores that a word association test did have an inherited component. There are several possible explanations for the contradictory findings. First, since a bimodal curve was found in the distribution of scores, especially noticeable for males, a Pearson product-moment correlation might not be the appropriate statistic to use. Second, in the Franklin study, responses to the stimulus words were given orally, whereas in the present study they were written by the examinees. Third, the stimulus words themselves were completely different for the two studies, although the method of scoring was the same. It would seem that further study is warranted to clarify the inconsistency of the results.

For the other variables there are some 18 correlation coefficients, significant at less than the .05 level of probability, listed in Table 6. Mothers and sons have the largest number of significant correlations. They are height (.62), Mental Arithmetic Test (.51), weight (.46), English Vocabulary Test, also (.46), Identical Blocks Test (.33), and Letter Concepts Tests (.32). The correlations between mothers and daughters which are significant at the .05 level are height (.37), Letter Concepts Test (.33), Spelling Test (.28), and Pitch Discrimination Test (.25). Fathers' scores correlated with sons' scores, significant at the .05 level, for the following variables are Spelling Test (.45), Pitch Discrimination Test (.36), weight (.34), English Vocabulary Test (.32), and Symbol Comparison Test (.27). Significant father-daughter correlations are height (.49), Pitch Discrimination Test (.31), and Identical Blocks Test (.30). There does not seem to be any trend towards correlations with the mothers' scores being any higher or lower than the fathers' scores for either sons or daughters. This seems to refute any conjecture about the environmental power of the early rearing of the mother over that of the father (Conrad & Jones, 1940).

The conclusion is reached that there are significant similarities between parents and their children, which in most cases cannot be explained by reference to significant similarities between the fathers and mothers.

The second hypothesis stated that the similarities between parents and their children might be explained by hereditary components. It had been stated earlier that correlational methods leave much to be desired in determining whether a trait has a large hereditary component because environmental influences cannot be partialed out. The exception to this statement occurs when there are family correlations of traits which show significant sex differences in their average scores. These differences might occur if the trait were determined by a gene on the X chromosome, i.e., sex-linked. In fitting correlational data to the sex-linked model, we do not need to know whether the gene determining the trait is dominant or recessive, because the coefficients will be the same. From the model we can make a prediction of the order of magnitude that these coefficients will take: Fa-Dau $\cong$ Mo-Son $>$ Mo-Dau $>$ Fa-Son $\cong$ Fa-Mo $\cong$ 0. The family correlation coefficients for the Identical Blocks Test fit these ordered magnitudes almost exactly. This is strong evidence that the trait of spatial visualization, as measured by the Identical Blocks Test, is sex-linked, and, furthermore, since males have a higher average score than females on the test, it suggests that a high score on the trait is recessive. Two other variables, which showed sex differences and gave ordered correlations very close to those predicted by the model, are height, which has only the father-son coefficient out of order, and the Mental Arithmetic Test, which has only the father-daughter coefficient out of order. Judging from correlations reported in other studies (Bayley, 1954; Pearson & Lee, 1903), height has been found to be rather evenly dependent on both the fathers' and mothers' genetic influences. Therefore, it would seem tenuous to attribute a sex-linked gene as part of the hereditary component for height, especially since there is also a significant correlation between fathers' and mothers' heights.

Spelling ability, as measured by the Spelling Test, reflected a sex difference, with females averaging higher than the males. However, the data fails to fit the sex-linked model, because the highest correlation coefficient is between fathers and their sons and the lowest between fathers and their daughters. Just the reverse should hold true. It would seem that additional data are needed, or the present data fitted to another model, to explain the relationship between parents' and their children's scores on the Spelling Test.

It might appear that the correlation coefficients given in Table 6 for the Identical Blocks Test and for the Mental Arithmetic Test are too low to make any judgment about the possibility of their having hereditary components. A comparison with theoretical phi coefficients for various gene frequencies will demonstrate that the magnitude of the coefficients depends upon the gene frequency and not upon the degree to which the genetic-environmental interaction depends upon the hereditary component. Table 7 gives the theoretical phi coefficients for several gene frequencies compared to the correlation coefficients of the Identical Blocks Test and the Mental Arithmetic Test corrected for attenuation.

It should be borne in mind that probably neither phi coefficients nor Pearson r's are the proper statistics to show these family relationships since the presence of the single zero cell in a sex-linked distribution (see Figure 8) would make the distribution somewhat curvilinear. However, the actual bivariate distribution of father-daughter scores on the Identical Blocks Test was tested by an eta coefficient for evidence of curvilinearity. The resulting correlation ratio of .40 was found to be nonsignificantly different from the Pearson r of .30. It was concluded that since the actual distribution was not significantly curvilinear, the Pearson r, while probably an underestimation, would be a good approximation.

TABLE 7

Corrected and Theoretical Family Correlations of the Mental Arithmetic Test and the Identical Blocks Test Scores

		Pearson r's Corrected for Attenuation		Theoretical Phi		
	N	Mental Arith.	Identical Blocks	20%[a]	50%[a]	60%[a]
Father-Mother	99	.07	.05	.00	.00	.00
Father-Son	51	.08	.03	.00	.00	.00
Father-Daughter	63	.21	.36	.41	.58	.61
Mother-Son	50	.62	.41	.41	.58	.61
Mother-Daughter	64	.25	.22	.17	.33	.38

[a] Based on these gene frequencies.

Both the Identical Blocks Test and the Mental Arithmetic Test showed by their correlational patterns that their hereditary component best fits the sex-linked model. This means that the genes responsible are located on the X chromosome. Since there are 23 pairs of chromosomes in the human female, it is highly improbable that two out of ten variables should be found on the same chromosome. Another explanation might be that the same gene through pleiotropic effects is responsible for both the Mental Arithmetic and the Identical Blocks Tests. The intercorrelations between these tests are .51 for mothers, .31 for fathers, .28 for sons, and .35 for daughters. This means that these tests have from 9% to 25% of their variance in common. It does not seem likely that a covariance this small is strong enough to account for the same genetic component influencing the family correlations. It is more likely that two separate genes on the X chromosome are responsible for the two traits.

In a further check, comparing mothers and sons, each of whom had standard scores of over 500 on both the Identical Blocks Test and the Mental Arithmetic Test, it should be noted that if one gene were responsible for both variables, the same mother-son pairs would be expected to be high on both tests. However, out of 12 mother-son pairs, where each of them scored over 500 on the Identical Blocks Test, only eight of the pairs also scored above 500 on the Mental Arithmetic Test. This reflects a chance distribution since the probability is .194 computed by the binomial test (Siegel, 1956). Out of 14 mother-son pairs, where each scored over 500 on the Mental Arithmetic Test, only eight of them also scored above 500 on the Identical Blocks Test. Again, this could easily happen by chance, because the probability level here is .395 computed by the binomial test. Although it has been pointed out that the effects of genes are manifold and not in a one-to-one relationship (Fuller & Thompson, 1960; Thompson, 1957), it is felt that even though the two tests have some variance in common, it is not attributable to the genetic component. Therefore, it is concluded that each test has an independent hereditary unit which appears to be sex-linked recessive. This conclusion satisfies the second hypothesis.

It is curious to note that Galton (1869) may have spotted the sex-linked characteristics of spatial visualization and general reasoning ability. Galton alludes to this by noting that scientific men do not seem to have as many eminent fathers as do some of the other professions he studied. Both traits show up more often among scientists and engineers than in other occupations. Ironically, the genetic import of this observation escaped him, and he attributed the above phenomena to an environmental influence saying, "Scientific men owe much of their training to their mothers...it therefore appears to be very important to success in science that a man should have an able mother." He thought this was brought about by the mothers' early child-rearing practices of teaching their sons to search for truth. In fairness to Galton, it should be noted that he did not have knowledge of sex-linked traits as such although it was generally known that color blindness passed through the mother's side of the family.

The only other study utilizing correlations between parents and children with variables similar to the present study was Willoughby's study (1927, Ch. 1), which was mentioned previously. In his study he used subtests taken largely from various intelligence tests. To make comparisons with the tests used in the present study, it is necessary to choose tests which, from their description, appear to be highly similar. To compare the

Identical Blocks and Mental Arithmetic Tests, let us examine the data from Willoughby's Arithmetic Reasoning Test and Geometric Forms Test. We find that, for both tests, the lowest family correlation is between fathers and sons; .16 and .14 for the Arithmetic Reasoning and Geometric Forms Tests, respectively. The present study finds also that father and son correlations are the lowest, although the magnitudes for Willoughby's tests are somewhat higher than those for the Mental Arithmetic and Identical Blocks Tests. The slightly higher correlation coefficient might be due to the high correlations between fathers and mothers in Willoughby's study, for they are .34 for the Arithmetic Reasoning Test and .25 for the Geometric Forms Test. In fact, all the mother-father correlations in Willoughby's study were much higher than in the present study, indicating a great deal of homogamy between parents.

There were two other correlational patterns in the present study markedly similar to Willoughby's. The first one, involving knowledge, was his Sentences Test, a measure of vocabulary through recognition. This test had its lowest correlation coefficient (.11) between fathers and daughters. Interestingly, the lowest family correlation coefficient for the English Vocabulary Test in the present study was .10, also between fathers and daughters. The second one, involving perceptual speed was Willoughby's Symbol-digit Substitution Test. It had its highest correlation coefficient between fathers and sons, .32, and also in the present study a correlation of .27 between fathers and sons proved to be the highest family correlation for the Symbol Comparison Test.

Dichotomic Analysis

To check our third hypothesis, that the hereditary components are of the discrete or segregated type, we turn to the technique previously explained, that of dichotomic analysis.

The results of the dichotomic analysis of the Symbol Comparison Test are given in Figures 9 and 10. The graph in Figure 9 shows hypothetical percentages of the population exhibiting recessiveness fitted to an autosomal model by use of chi-square with the assumption that a low score is recessive. Figure 10 shows exactly the same type of fit using chi-square but this time the assumption is that a high score on the test is recessive. The details of each chi-square goodness-of-fit test for each hypothesized dichotomy are shown in Figures D-1 and D-2 in Appendix D. Data, shown in Figures 9 and 10, indicate that there are several hypothetical percentages where reasonably good fits coincide between the father-son data and the mother-daughter data. In both graphs, a frequency of 10% seems like a good fit. However, reference to the actual chi-squares in Figures D-1 and D-2 shows that, when $q^2 = .10$, one of the cells has an expected frequency of less than five. Chi-squares which do not meet this requirement are suspect. Experience in working with dichotomic analysis makes one wary of fits where the hypothetical frequency of the population is 10% and below, or 90% and above, since the small number of cases involved in this study almost always result in a cell having a theoretical frequency of less than five. Again turning to Figure 9, better fits would be at the percentages near 20%, assuming a low score to be recessive, or near 60% when a high score is assumed to be recessive. Judging from the p values (.35 for the fit of the father-son data, .70 for the mother-daughter data), the best fit

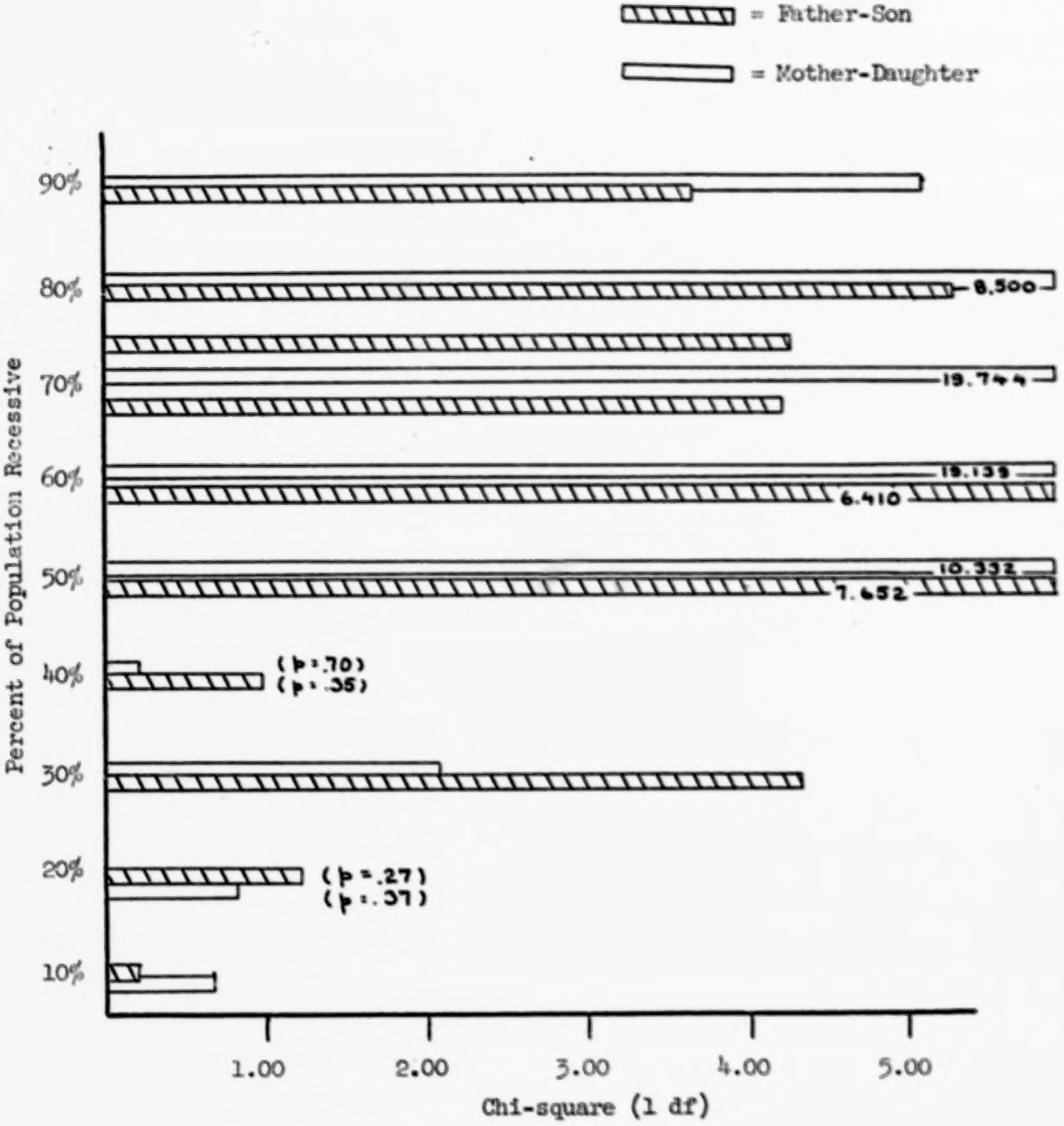


FIG. 9. SYMBOL COMPARISON TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (Low Score = Autosomal Recessive)

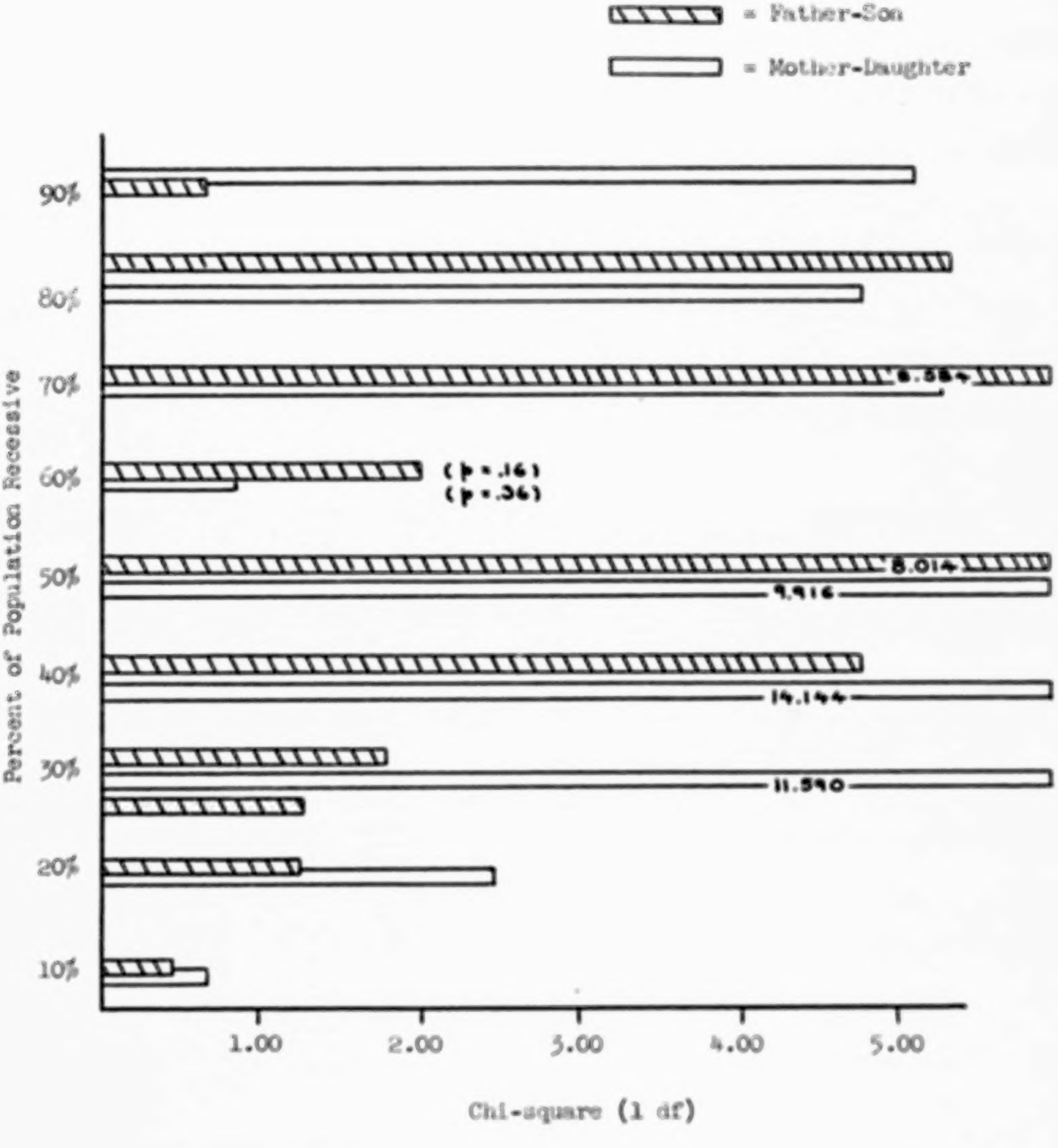


FIG. 10. SYMBOL COMPARISON TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Autosomal Recessive)

occurs with the assumption that scoring low is recessive to scoring high and with the hypothesis that approximately 40% of the population manifests recessiveness. Therefore, it is concluded that there is good evidence that the trait of perceptual speed, as measured by the Symbol Comparison Test, has an underlying dichotomy revealed by the congruence of the father-son data with the mother-daughter data.

Figures 11 and 12 show graphs resulting from the dichotomic analysis of the Word Association Test. The first graph shows the hypothetical percentages of the population exhibiting recessiveness fitted to an autosomal model with the assumption that a low score is recessive. Figure 12 is graphed with the assumption that a high score is recessive. Details of the chi-square goodness-of-fit tests are given in Figures D-3 and D-4 in Appendix D. In Figure 11 the only possible congruence between the father-son data and the mother-daughter data is at the 10th percentile. However, as previously mentioned, any such fit at the extremes is likely to be spurious because of the small size of the sample. There is no evidence of congruence between the father-son and mother-daughter data in Figure 12.

We conclude that there is no evidence for an underlying dichotomy in the distribution of Word Association Test scores in spite of the fact that a plot of the male scores showed evidence of bimodality.

Since males averaged higher than females on the Mental Arithmetic Test, the assumption was made that a high score was recessive to a low score, and the data were only fitted to a sex-linked recessive model. In Figure 13, the father-daughter data are compared to the mother-son data. We have already mentioned the fact that in the case of the sex-linked model, one of the cells has a theoretical value of zero. Legitimately, then, the chi-square

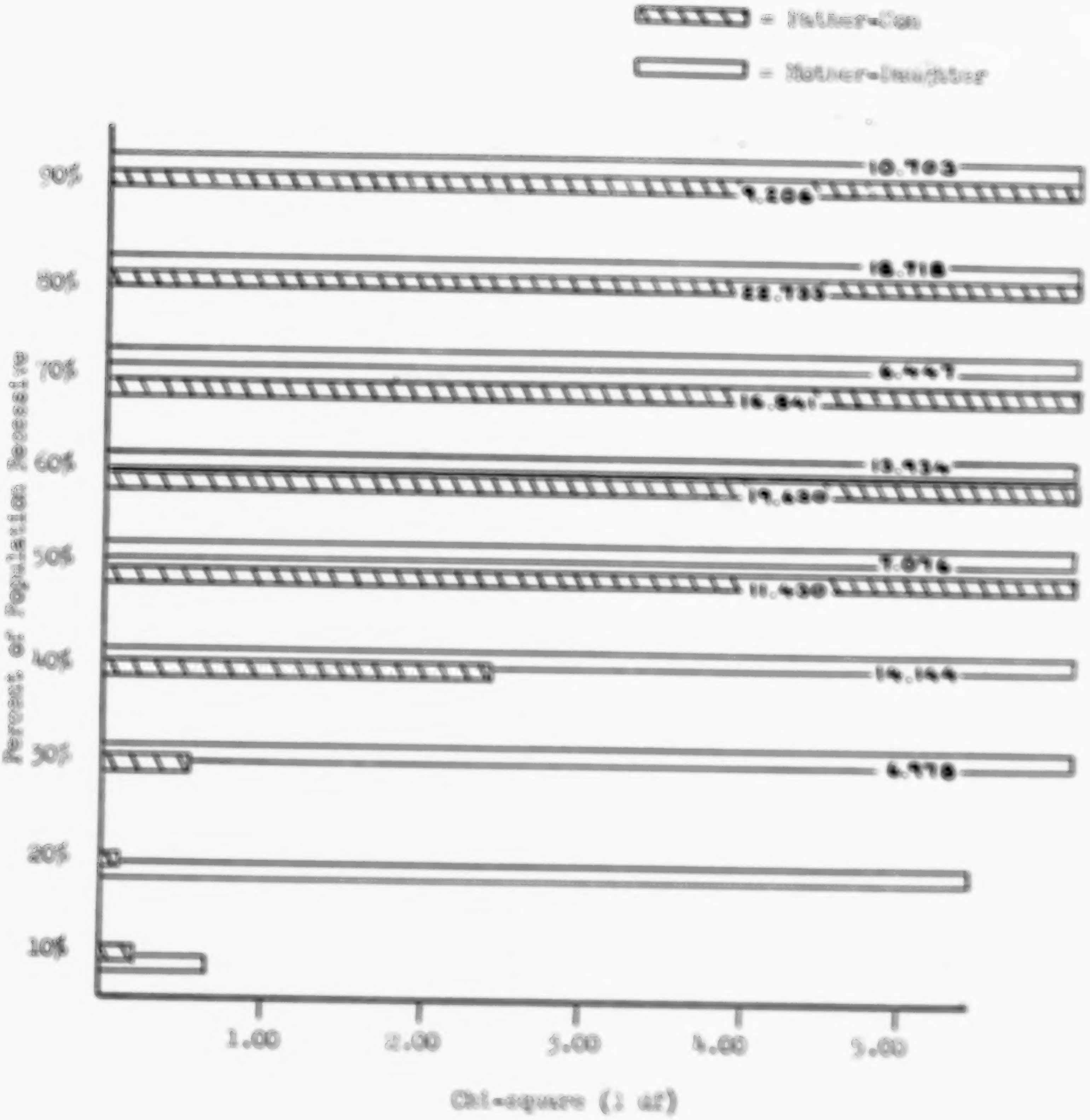


FIG. 11. WORD ASSOCIATION TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (Low Score = Autosomal Recessive)

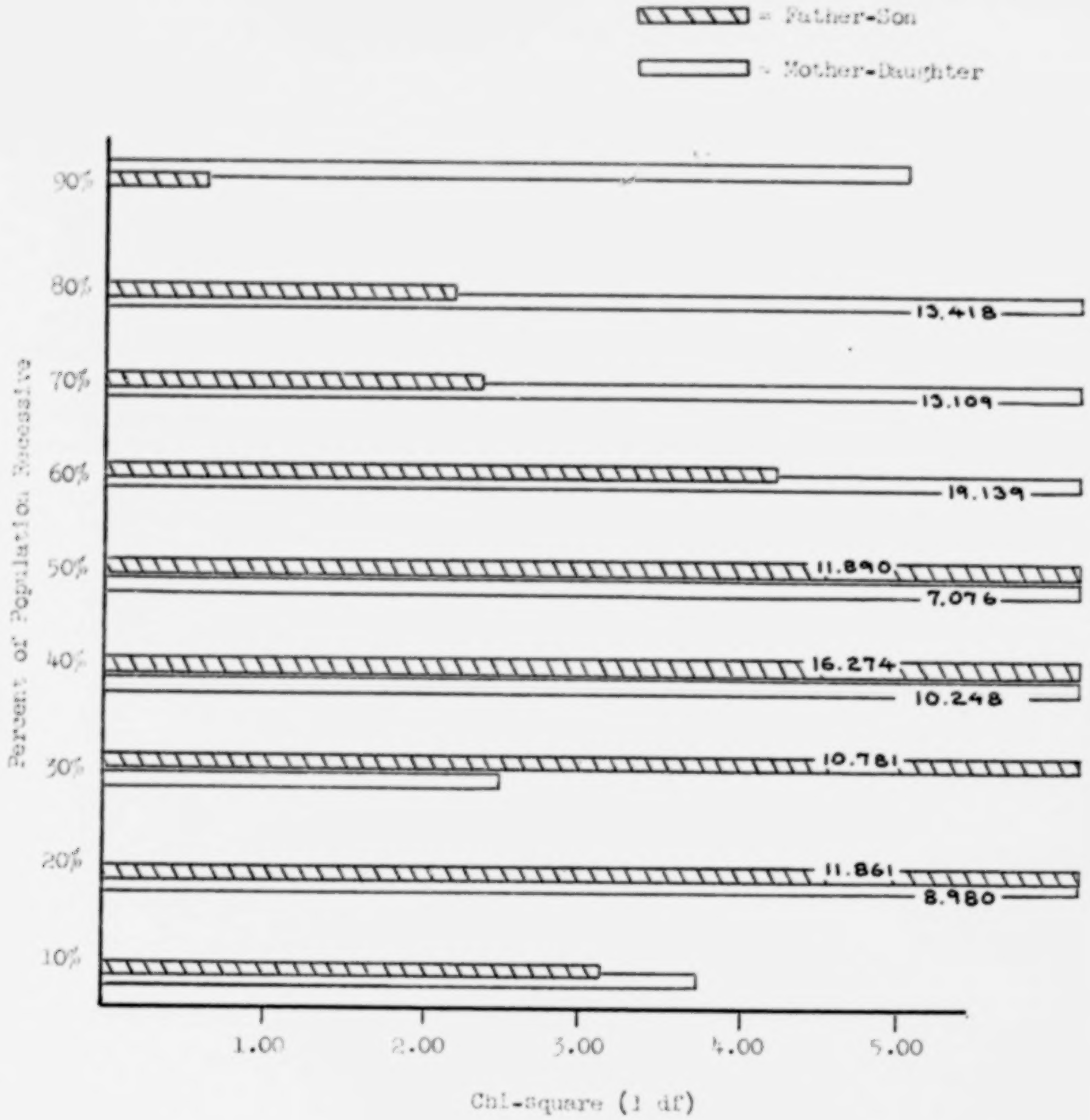


FIG. 12. WORD ASSOCIATION TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Autosomal Recessive)

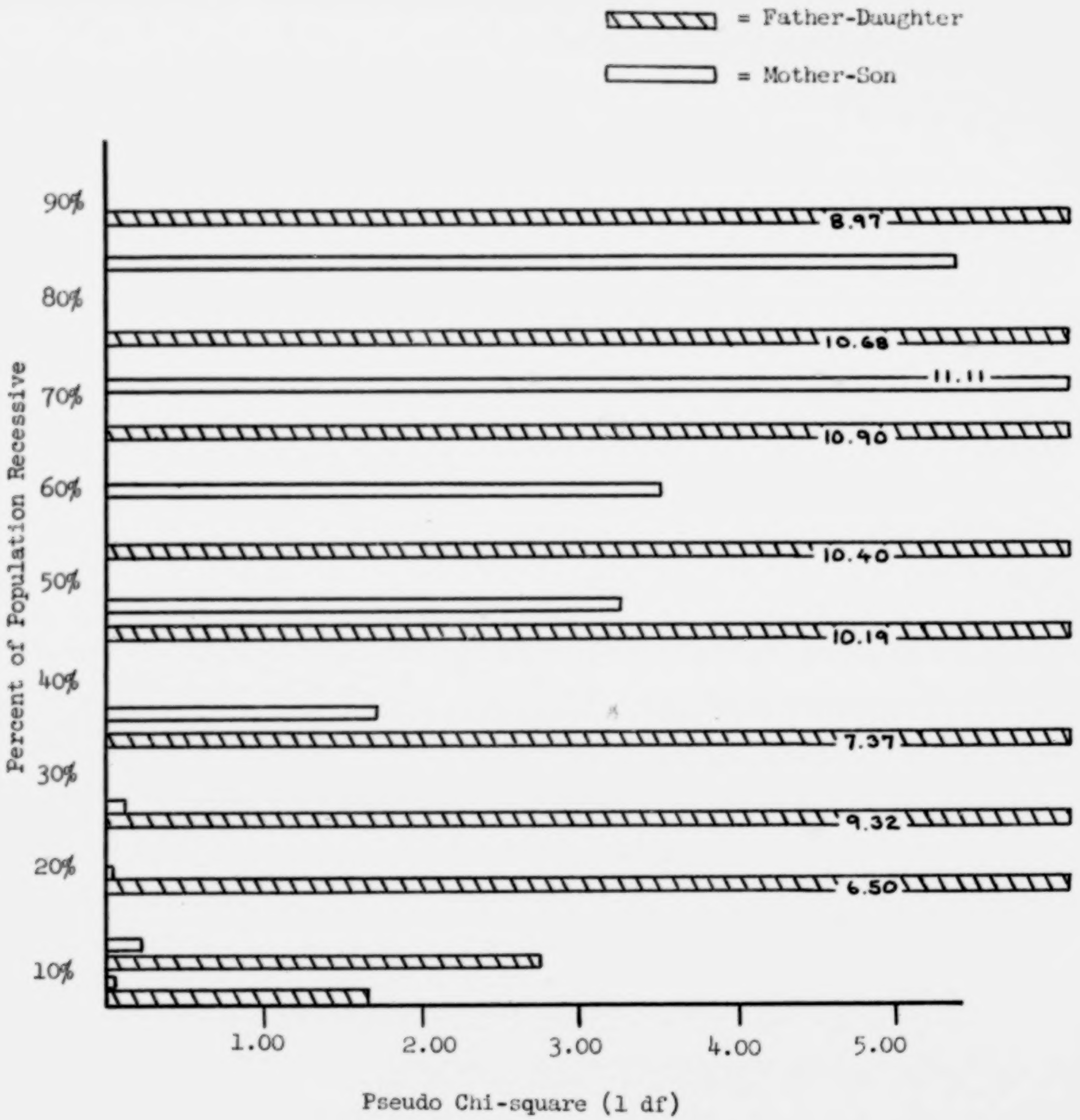


FIG. 13. MENTAL ARITHMETIC TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Sex-linked Recessive)

test should not be applied; hence, we have called these "pseudo" chi-squares. Details of these psuedo chi-squares are given in Figure D-5 in Appendix D. While there are some fairly good fits of the data to the model, using the mother-son data, nowhere between the 10% and 90% hypothetic population values do the father-daughter data give any indication of a good fit. We must conclude that there is no evidence for an underlying dichotomy for a general reasoning ability as measured by the Mental Arithmetic Test.

The graphs in Figures 14 and 15 show the results of the dichotomic analysis of the Pitch Discrimination Test data. Figure 14 gives the hypothetical percentages of the population exhibiting recessiveness, when the assumption is made that a low score is recessive. There is a possible congruence of fits to the model, for both the father-son data and the mother-daughter data, near the 10th percentile but it is far from convincing. Figure 15 gives several percentages which might illustrate a good fit when the assumption is made that a high score on the test is recessive. A nearly perfect fit comes at approximately the 20th percentile. The p values are .92 for the father-son data and .89 for the mother-daughter data. This would mean that an underlying dichotomy exists such that 80% of the population has the ability to detect small differences in the change of pitch as measured by this test. In applying dichotomic analysis to twin scores on Seashore's Pitch Discrimination Test (Stafford, 1959), a split was found such that approximately 45% of the population had the ability to detect small differences in changes of pitch, and 55% lacked it. It is difficult to see how the contrary findings between this and the present results could be due to sampling error, but so many variables differed between the two studies

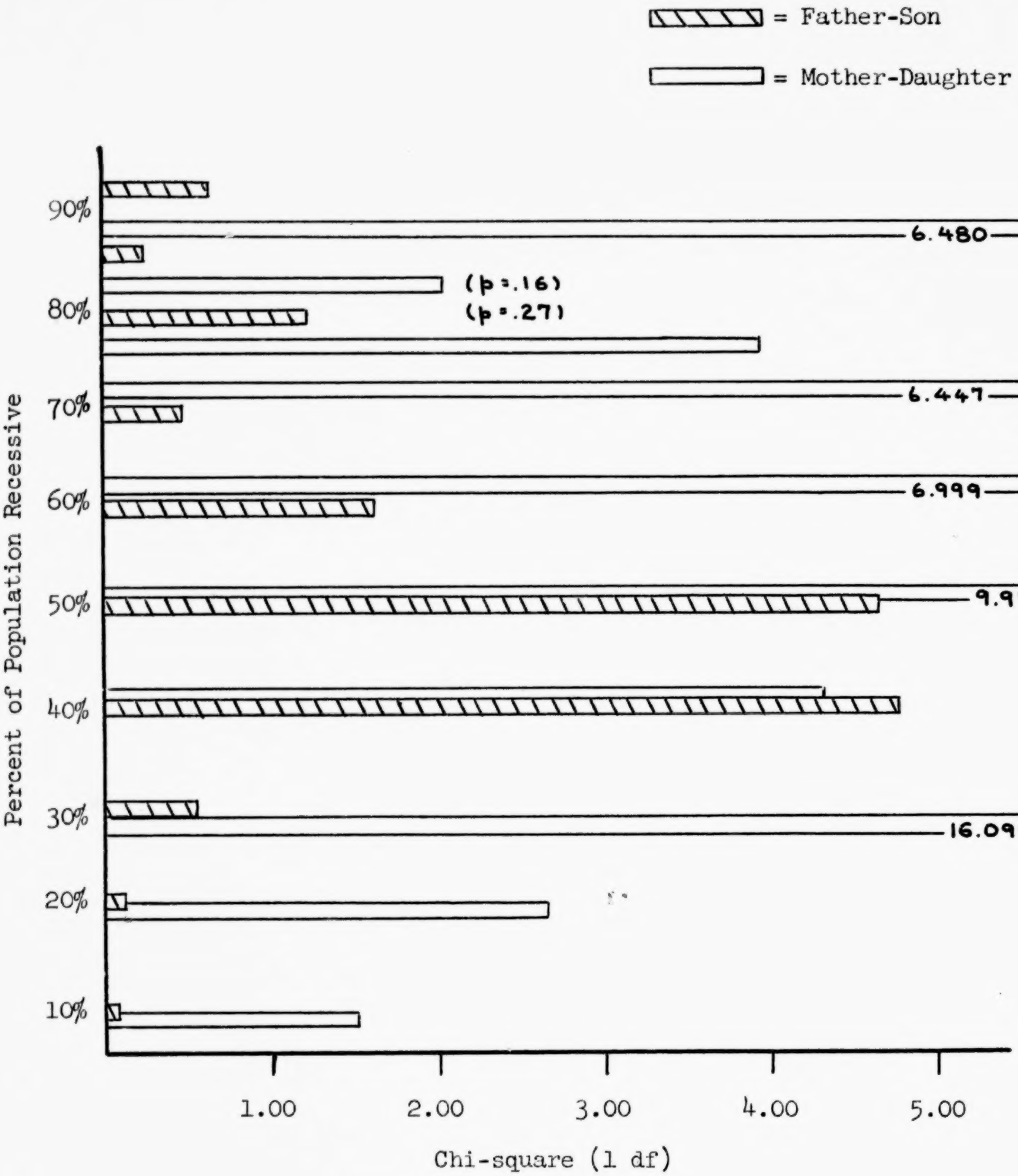


FIG. 14. PITCH DISCRIMINATION TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (Low Score = Autosomal Recessive)

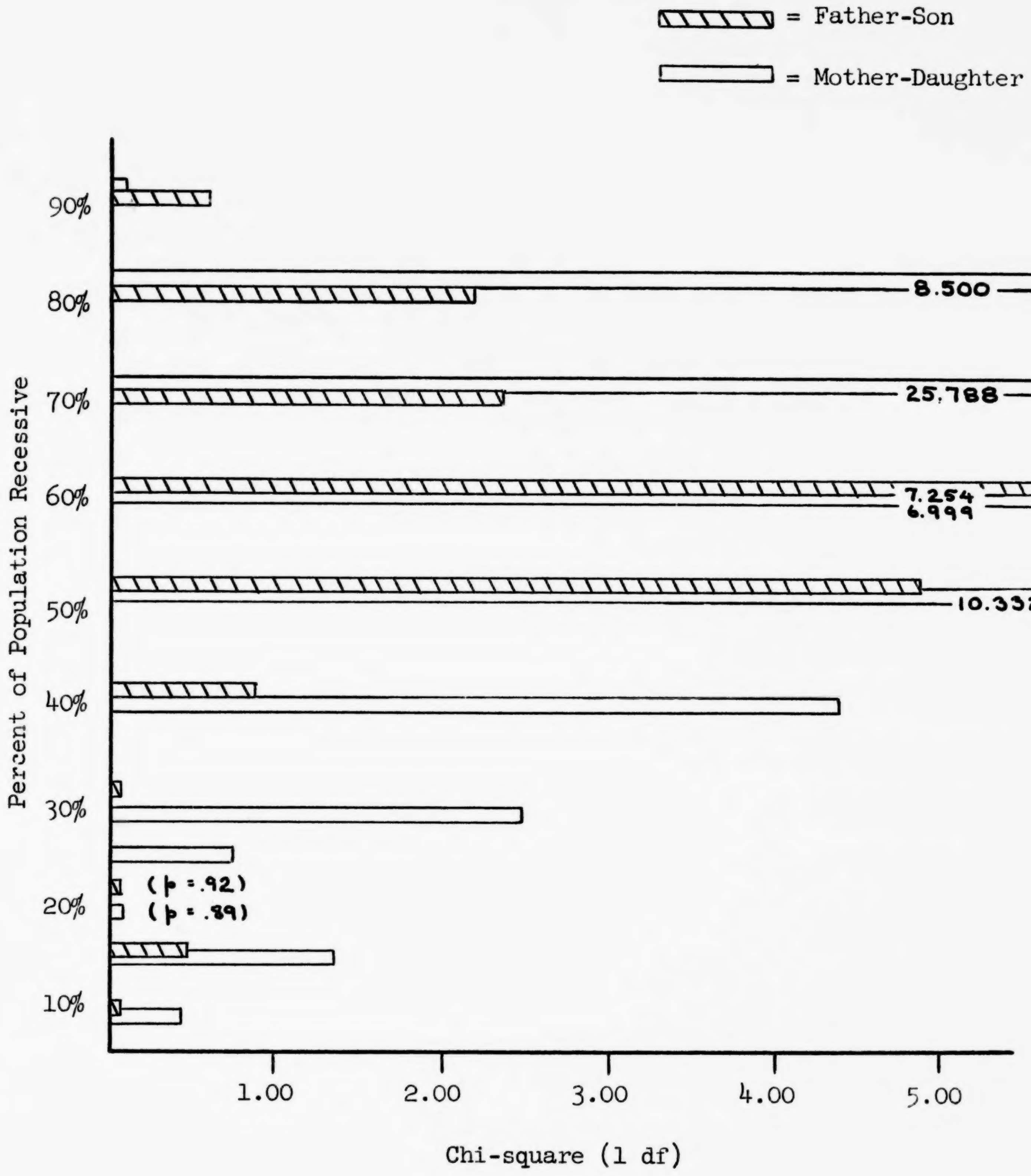


FIG. 15. PITCH DISCRIMINATION TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Autosomal Recessive)

that no single reason can be proffered for the discrepancy. The details of the chi-square goodness-of-fit tests are given in Appendix D, Figures D-6 and D-7, respectively.

The results of the dichotomic analysis of the Letter Concepts Test data are given in Figures 16 and 17. Figure 16 shows the graph in which the Letter Concepts Test scores of parents and their children are fitted to an autosomal model with the assumption that a low score is recessive, and in Figure 17 with the assumption that a high score on the test is recessive. The details of the chi-square goodness-of-fit tests for these graphs are given in Figures D-8 and D-9 in Appendix D. In examining Figure 16, the only possible place where there might be congruence between the mother-daughter data and the father-son data is at the 20th percentile. At this point, the mother-daughter data fits the model fairly well with a p value of .37, while the father-son data has a probability of .27. This closely approximates the model, but the chi-square shows an expected frequency in one cell of 4.4, which is very marginal. No evidence exists in Figure 17 for either the mother-daughter data or the father-son data, which suggests an underlying dichotomy at any hypothetical percentage. From the analysis of this variable, it is concluded that inductive reasoning, as measured by the Letter Concepts Test, does show minimal evidence of an underlying genetic component at the 20th percentile.

The dichotomic analysis of the Spelling Test is based upon the assumption that a low score on the test is recessive to a high score, since there was a significant sex difference between the average scores of males and females, favoring the latter. Figure 18 shows the graphs comparing the father-daughter data with the mother-son data. While there is a suggestion

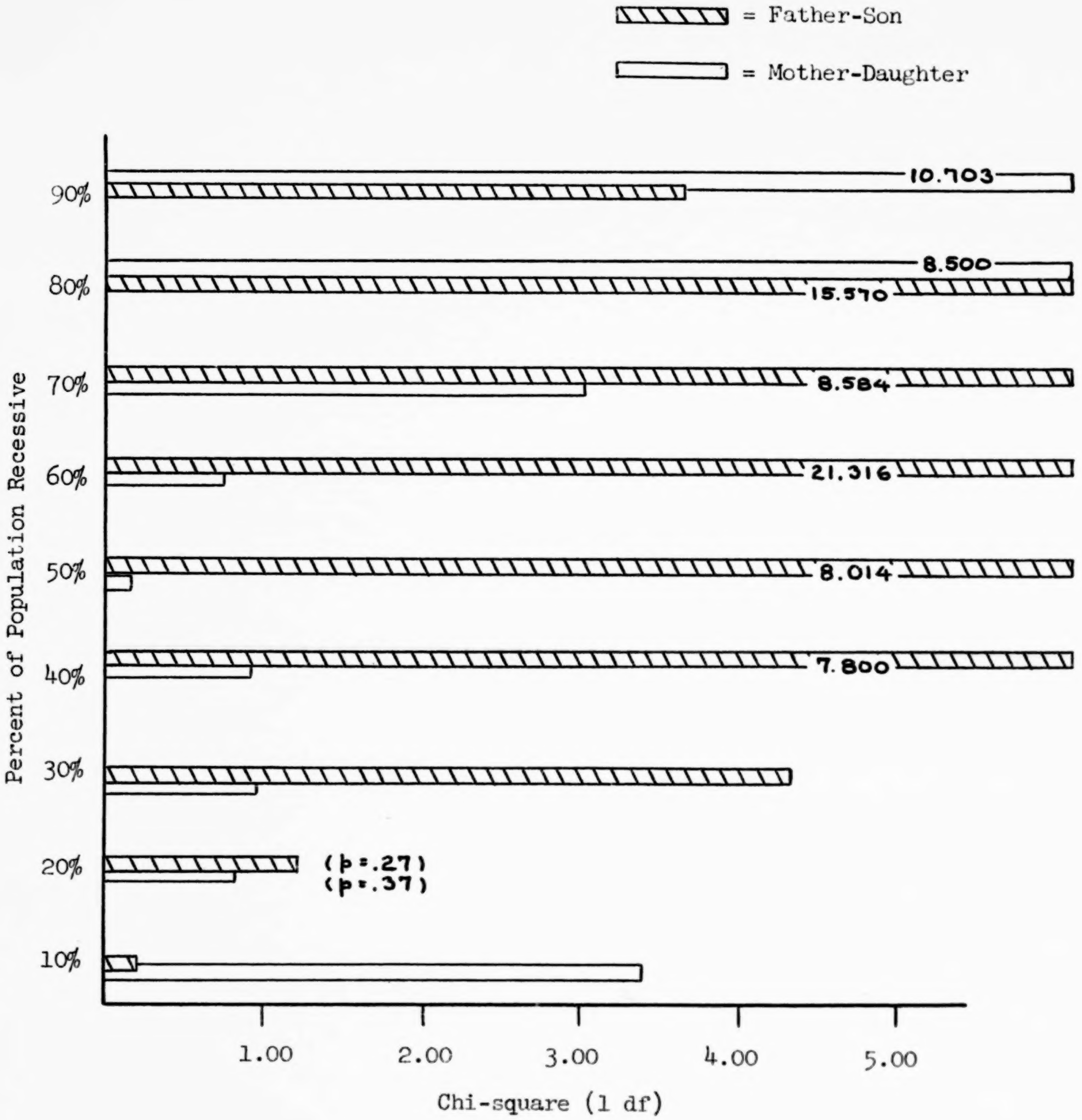


FIG. 16. LETTER CONCEPTS TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (Low Score = Autosomal Recessive)

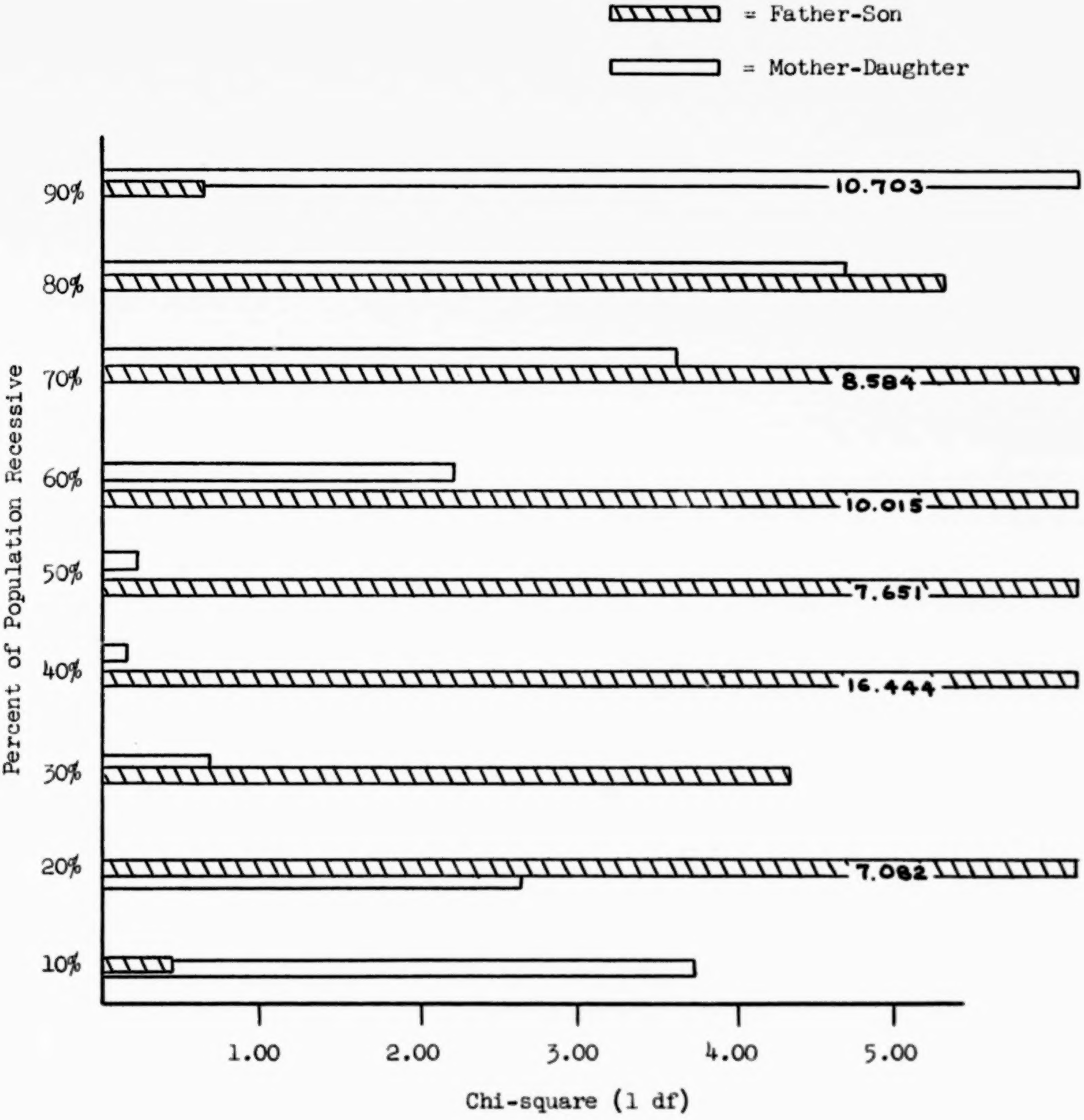


FIG. 17. LETTER CONCEPTS TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Autosomal Recessive)

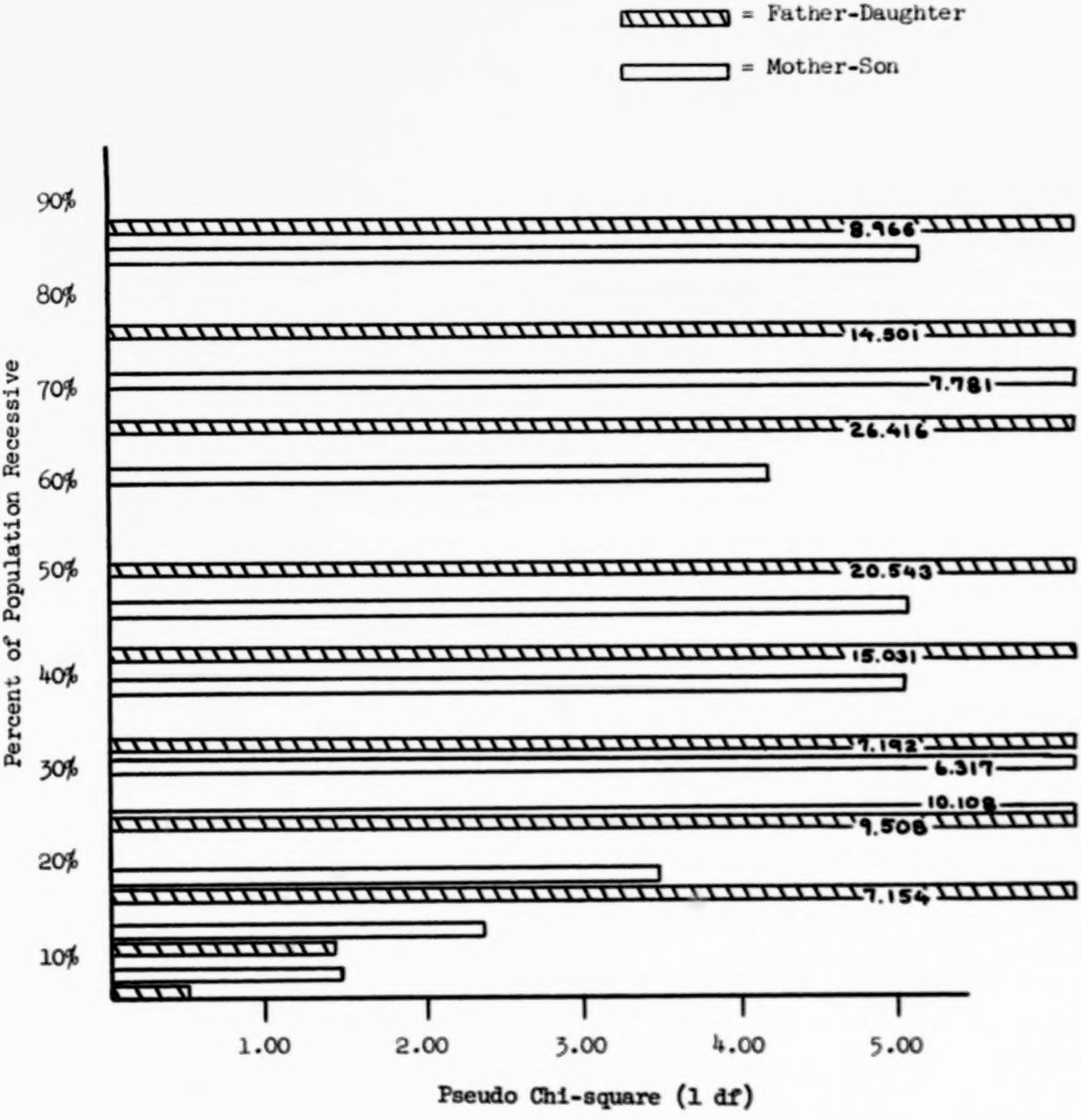


FIG. 18. SPELLING TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (Low Score = Sex-linked Recessive)

that some congruence lies in the 8% to 10% range, it might be due to the unreliability of the method at the extremes when such a small population is employed. Details of the pseudo chi-squares used in testing the fit in Figure 18 are given in Figure D-10 of Appendix D. No evidence is obtained from this study that the Spelling Test scores have an underlying dichotomy, although some evidence was found for an underlying dichotomy when twin data were analyzed by dichotomic analysis (Stafford, 1959). Unfortunately, different lists of words were used in the two studies making comparison that much more difficult. Further investigation is needed to resolve the apparent discrepancy between the two studies.

Figure 19 shows the comparison of the father-daughter data on the Identical Blocks Test with the mother-son data fitted to a sex-linked model. Since males averaged significantly higher than females, dichotomic analysis was only run with the assumption that a high score on the test was recessive to a low score. The only population percentage that shows any possible congruence between the father-daughter and mother-son scores is at the extremes in the unreliable areas. Therefore, it is concluded that there is no evidence of a unitary genetic component in spite of the fact that the correlational analysis suggests that a gene on the X chromosome is primarily responsible for the hereditary component. Details of the pseudo chi-squares are given in Figure D-11 in Appendix D.

Figures 20 and 21 give graphs showing the dichotomic analysis of the English Vocabulary Test data, the first graph having the assumption that a low score on the test is recessive to a high score, and the second graph, Figure 21, is predicated upon the assumption that a high score is recessive

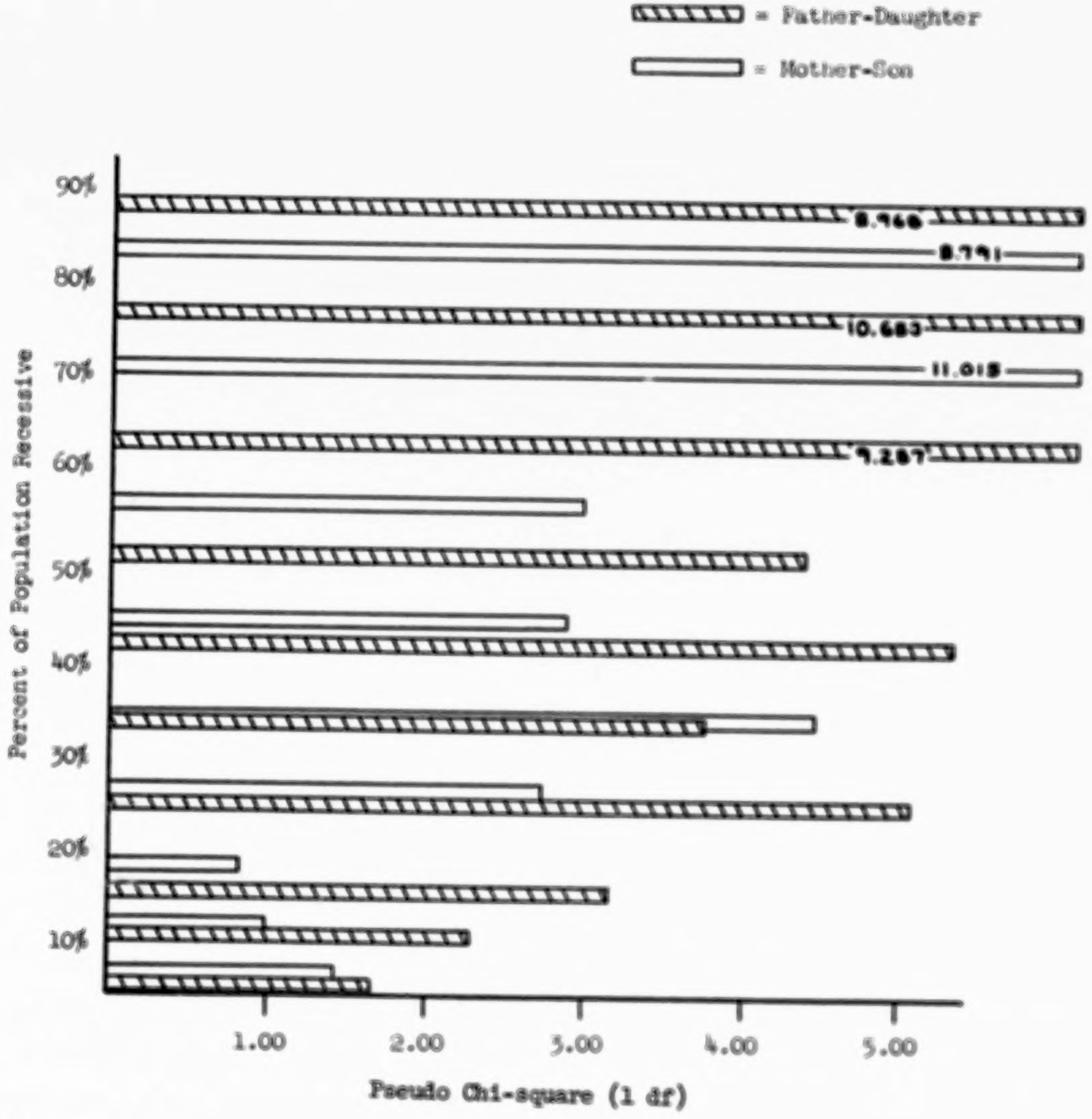


FIG. 19. IDENTICAL BLOCKS TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Sex-linked Recessive)

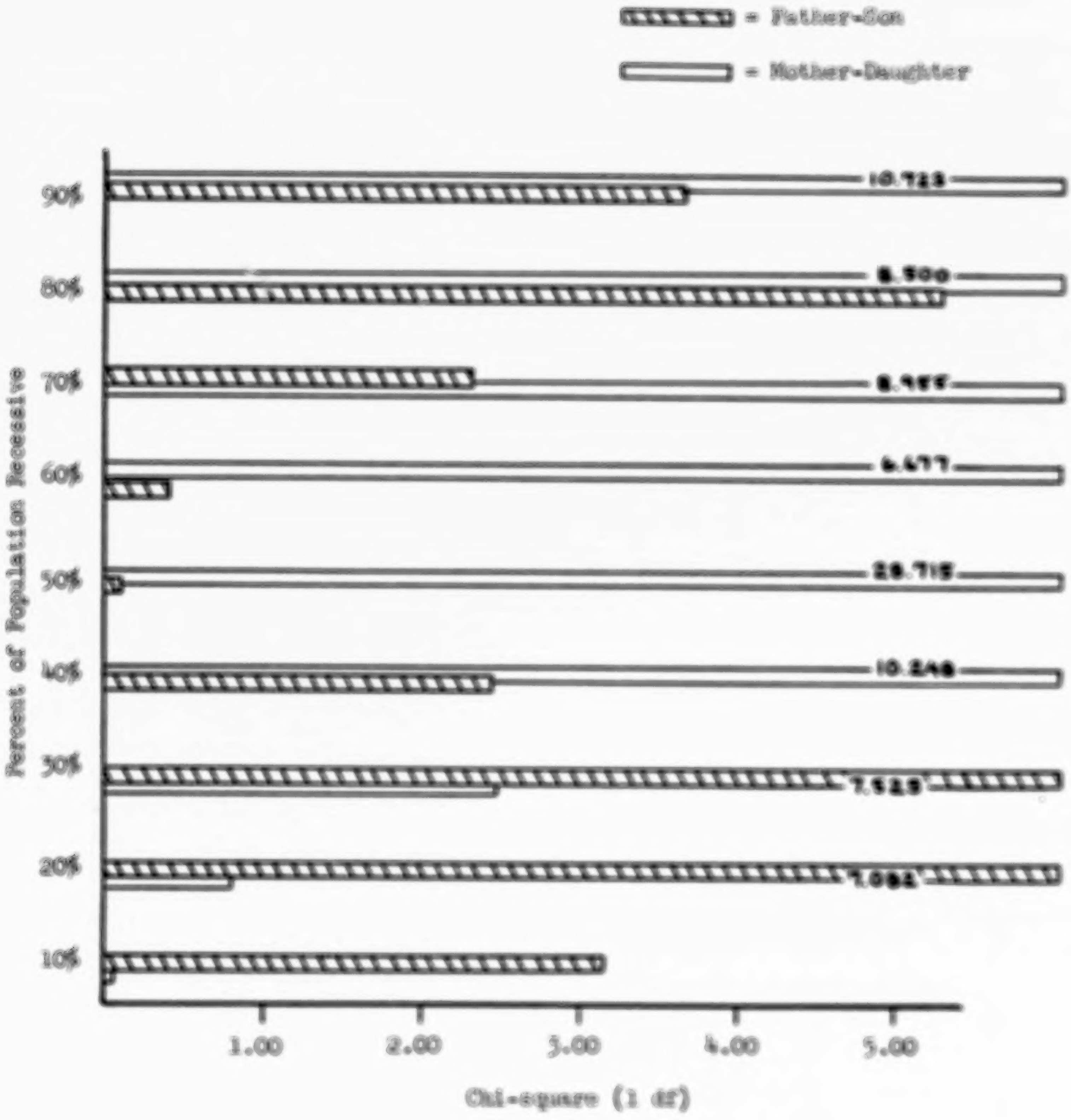


FIG. 20. ENGLISH VOCABULARY TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (Low Score = Autosomal Recessive)

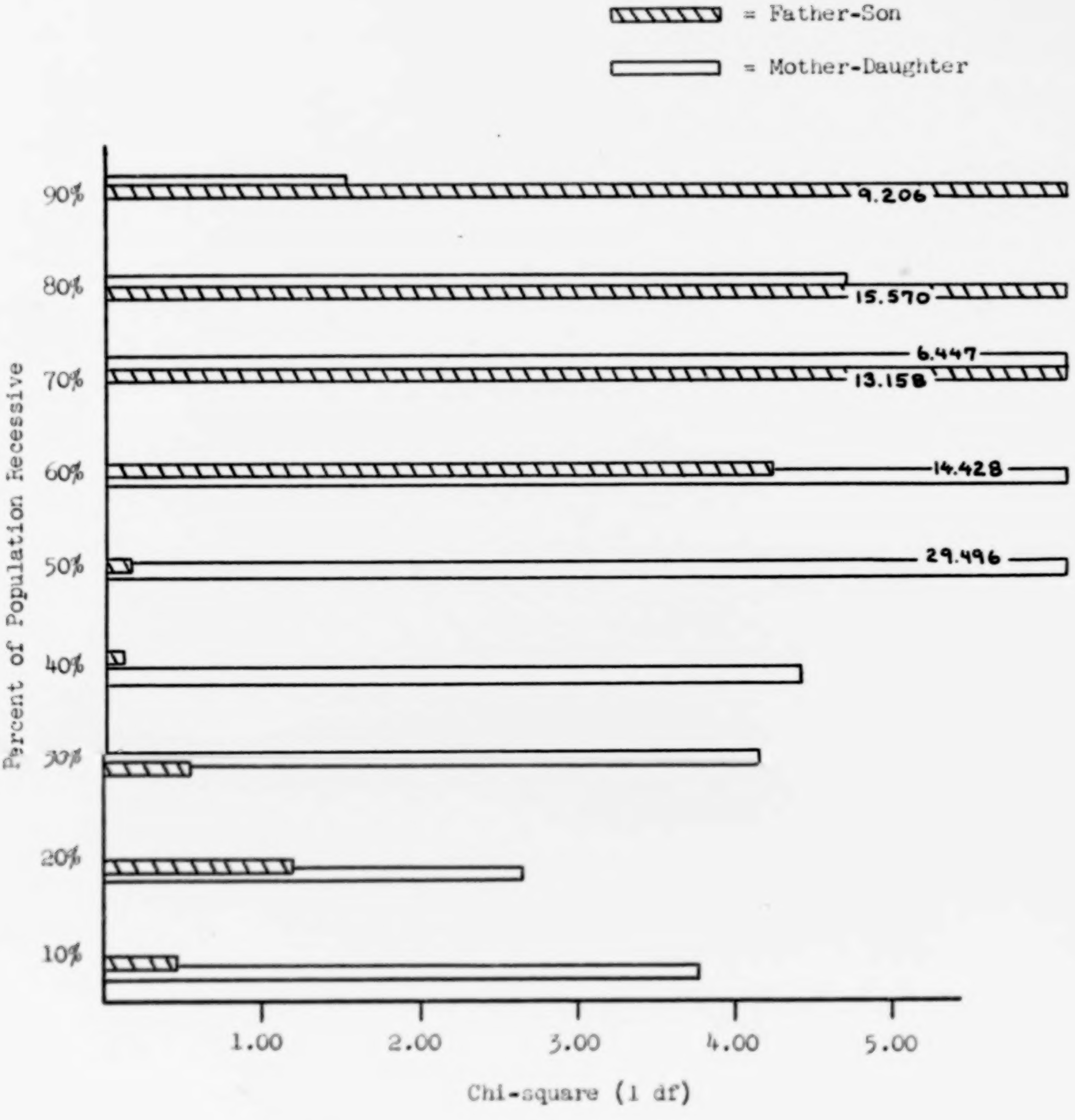


FIG. 21. ENGLISH VOCABULARY TEST. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Autosomal Recessive)

to a low score. Details of the chi-square goodness-of-fit tests are given in Figures D-12 and D-13 in Appendix D.

Examination of the graphs failed to show any particularly good fit between the father-son and the mother-daughter data on the English Vocabulary Test. It is possible that the high correlation previously noted between fathers and mothers on this variable may be serving to mask a possible dichotomy, or, of course, it may be there are not enough hereditary components involved in the acquisition of vocabulary to be observed by this method.

Sex differences favoring males in height made the assumption tenable that the data could be fitted to a sex-linked recessive model. By use of dichotomic analysis, the fit of the father-daughter and the mother-son data was checked for any possible congruence. The results are given in Figure 22. Ironically, the congruence is quite good for both sets of data where 15% of the female population would manifest dominance. Two findings make this percentage suspect. First, there was considerable homogamy evidenced by the correlation between fathers and mothers. Second, no other worker has reported any such pattern of correlations, as shown in Table 6, nor has anyone else found results suggesting that height is a sex-linked trait. It is entirely possible that this finding was due to sampling error. Perhaps another method should have been used to partial out sex differences prior to the dichotomic analysis. Referring all measurements to a standard score, regardless of sex differences, may have distorted the data somewhat, since women tend to marry men who are taller than themselves.

Practically the same comments can be made about weight. In Figure 23, there is shown the dichotomic analysis of the father-daughter and mother-son

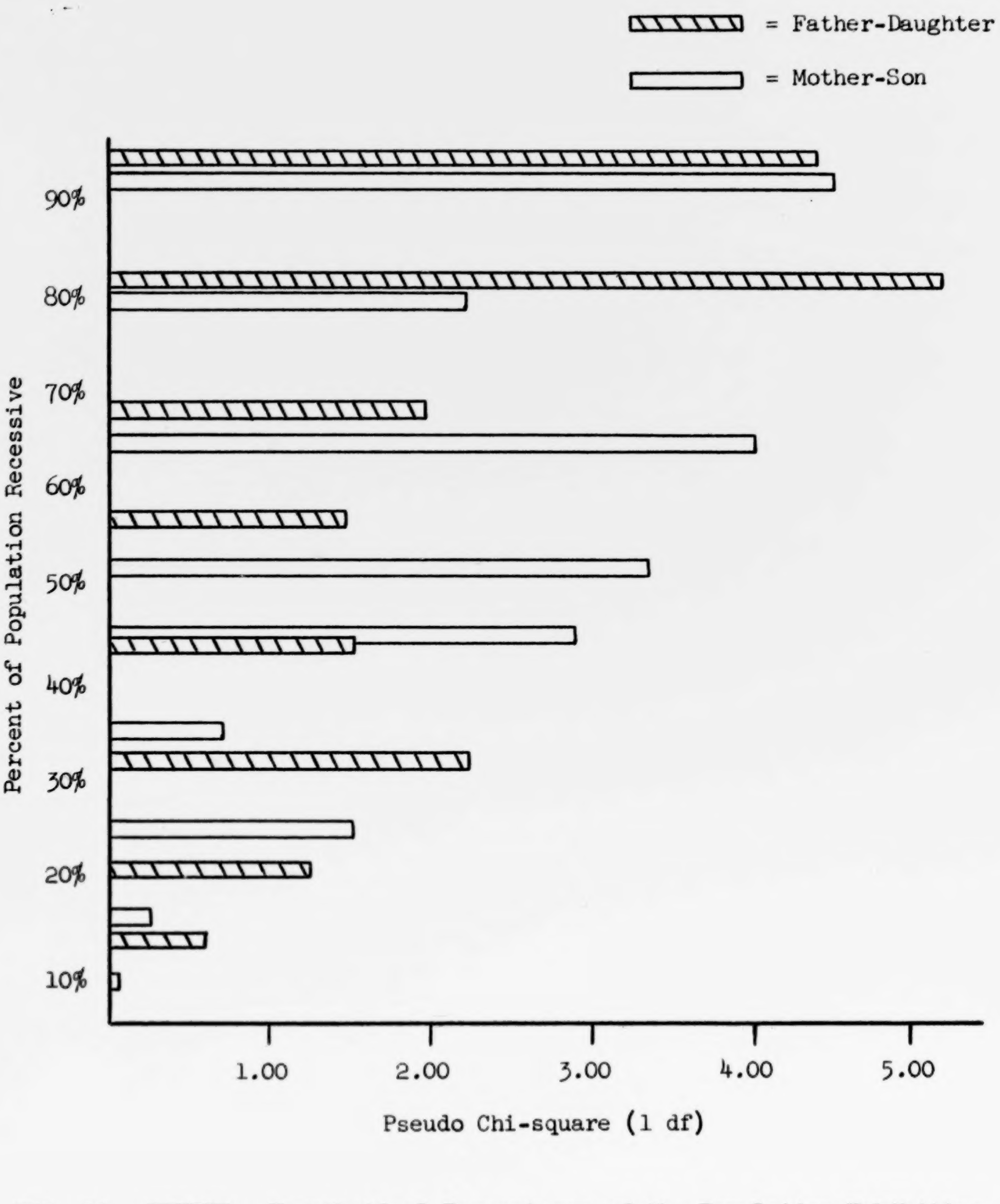


FIG. 22. HEIGHT. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Sex-linked Recessive)

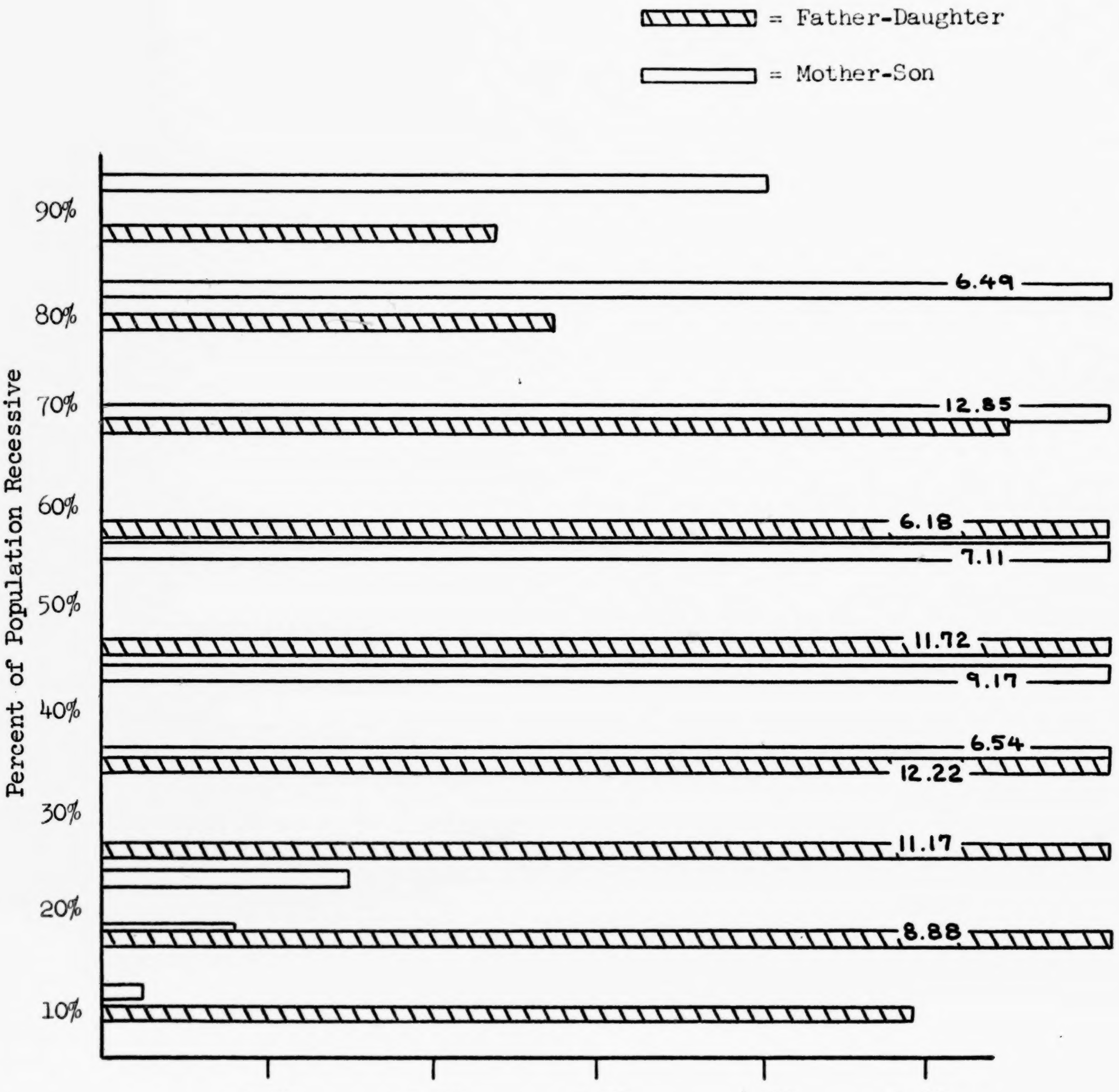


FIG. 23. WEIGHT. Hypothetical Percentages of the Population Exhibiting Recessiveness Fitted to a Genetic Model (High Score = Sex-linked Recessive)

data with the assumption, once again, that the trait is transmitted by a sex-linked recessive gene. However, unlike the findings for height, this time there are no points of congruence. Details of the pseudo chi-squares of height and weight are given in Figures D-14 and D-15, respectively, in Appendix D.

A summary of the results with conclusions drawn from this study and recommendations for future research will be given in Chapter VI.

Chapter VI

CONCLUSIONS AND RECOMMENDATIONS

Relation of the Data to the Hypotheses

This investigation of the similarities between parents and their children attempted to answer three questions. The first question was, "Are there any similarities between parents and their children on certain psychological traits which are unexplained by a similarity between the parents themselves?" The second question was, "Can this similarity between parents and their children be explained by hereditary components?" The third question was, "Are these hereditary components classified as the discrete or segregated type of inheritance?"

The answer to the first question is in the affirmative because significant similarities were found between either fathers and their children or between mothers and their children for all the variables in the study, with the exception of the Word Association Test. In this test, small correlations were found between fathers and sons, when their scores were correlated by a phi coefficient, but the result was not significant. The second part of the first question is answered affirmatively because no significant correlations were found between fathers and mothers, except for the English Vocabulary Test scores and their heights. This fact makes subsequent analyses of the parent-child data for the latter two variables suspect.

The answer to the second question is again affirmative. Analyses of the Identical Blocks and Mental Arithmetic Tests gave evidence that the relationship was due to a hereditary component. The evidence, in the form of unique familial correlational patterns, pointed to a sex-linked recessive gene as the major hereditary component. However, this was not borne out by the dichotomic analysis of these two variables. Although the Identical Blocks Test and the Mental Arithmetic Test are somewhat correlated, the best interpretation of all the facts is that there are two different genetic units responsible for these two traits, even though both units appear to be on the X chromosome.

The answer to the third question is again in the affirmative. The Symbol Comparison and Pitch Discrimination Tests, showed evidence of having an underlying dichotomy of the discrete type, since the best fits to an autosomal genetic model were at approximately the same percentages for the mother-daughter data as they were for the father-son data. The Letter Concepts Test also appeared to have an underlying dichotomy, although the evidence was not as cogent.

Possible Explanations of Negative Findings

Several of the other variables failed to agree with one or more of the three hypotheses stated for this study. Why did some of the variables fail to agree with these hypotheses and others agree?

It may be worthwhile to discuss the negative findings of this study and to offer some possible explanations for them. The only test that failed to meet the first hypothesis was the Word Association Test. Some possibilities as to why there are discrepancies between the findings of this study and that of Franklin (1945) have already been noted in Chapter V. It was pointed out that this might be due to (1) different populations; (2) different stimulus words in the two forms of the test; (3) the fact that the examinees' responses in the earlier study were oral, whereas in the present study they were written; and (4) the bimodal distribution obtained may have precluded the proper statistic being used in the analysis.

Several of the variables failed to meet the second hypothesis. There are several possible explanations for this:

(1) The tests were generally too short and/or were too unreliable.

(2) The motivation level among some of the volunteer subjects was not high enough to truly measure the variable.

(3) The tests were intercorrelated to such an extent that they may have masked some genetic components.

(4) Many of the variables had relatively large environmental components, making it difficult to observe the variance due to heredity.

Several of the variables also failed to meet the third hypothesis. In addition to the above possible explanations, we must add those which are unique for explaining the failure of the dichotomic analysis. These might have been:

(1) The hereditary components present depended upon a number of minor genes contributing cumulatively; hence, they were not revealed by the analysis.

(2) Sex differences in some tests may have been so large as to obscure an underlying dichotomy.

(3) Some of the genetic assumptions, i.e. absence of epistasis, complete penetration, or complete dominance, may not have been met.

(4) The genetic models to which the data in this study were fitted may not have been the most appropriate ones.

Another puzzling result of this study was the fact that the Identical Blocks and the Mental Arithmetic Tests showed evidence of possible sex-linked inheritance from the correlational analysis but failed to reveal any trace of a unitary component under the dichotomic analysis. One possible explanation of this discrepancy is that the sex-linked model posits that there shall be one cell with a theoretically zero frequency. A few cases kept appearing in this cell and may have prevented the hoped-for dichotomy from appearing. It is extremely difficult to calculate the exact number of discrepancies unless the underlying dichotomy is revealed. When this does not show up, all one can do is to take the fit giving the highest p value as the most likely point dividing the population. But there are two problems with this in the case of the Identical Blocks and Mental Arithmetic Tests. First, the p values are only descriptive since pseudo chi-squares were computed with an expected zero cell. Second, the percentages of a possible fit were quite different for father-daughter data than they were for mother-son data.

Examination of Figures D-3 and D-12 in Appendix D shows that the father-daughter data appear to be more discrepant than the mother-son data, inasmuch as more cases appear in the theoretical zero cell. All of the previous possible explanations may be cited again to account for this discrepancy. We might add two more. There is always a possibility that there was a mutation to another gene. Also, the possibility of illegitimacy cannot be ruled out. Of course, there may have been other genetic factors operating which are unknown.

Recommendations

After conducting a study of this size one comes to believe that several of the procedures or analyses might have been done differently. Also, as the study progresses, ideas occur which should be noted for other researchers. Therefore, it seems appropriate to offer recommendations for further research and suggestions to those who may want to replicate this study or attempt a similar one.

First of all, a larger sample would have had the advantage of allowing the data to be fitted to hypothetical dichotomies below 10% and above 90%, since a good fit to one of the models might have been found at these extremes. In obtaining a larger sample, it should be borne in mind that it must be as unselected and as heterogeneous as possible. It is very important that the individuals selected for the study try earnestly on all tests, for it would not improve the accuracy of the analysis to obtain more subjects, unless the reliability and validity of their scores were held to a high level.

Second, the tests should be longer to reduce the standard error of estimate and increase their reliability. Traits which are even more uncorrelated than those in the present study should be used. Possibly several tests measuring the same trait would allow them to be factor analyzed and factor scores computed to partial out the unique variance of the tests. In addition, other variables should be explored on a wider scale.

Besides partialing out age differences, sex differences should be partialed out as well as leaving the sex differences in (as was done in the present study) for comparison.

If underlying dichotomies are found which fit an autosomal model, a plot of father-mother-child test scores might substantiate whether the data fitted the dominant or recessive hypothesis. Then family pedigrees could be inspected for concordance to the posited model.

Another phase of the study would be to have stepparents' and adopted children's test scores for controls in the correlational analysis to make a comparison with the true parents and their own children's test scores.

In conclusion, it would seem that the analysis of parents' and children's test scores by correlational means and by dichotomic analysis offers new and important methods for answering the old question of how nature and nurture interact to produce behavior. Although, only a few variables showed evidence of having definite hereditary components, even fewer variables showed evidence of definitely not having hereditary components.

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Appendix A

APPENDIX A

Schools Cooperating in This Study

April - June 1960

Council Rock High School, Newtown, Pennsylvania

Dr. George E. Taylor, Supervising Principal
Mr. Thomas W. Elliott, Guidance Department
Mrs. Emilie Gaither, Guidance Department

Ewing High School, Ewing, New Jersey

Dr. Gilmore J. Fisher, Superintendent
Mr. Raymond Steketee, Principal
Mrs. Gladys L. Jensen, Director of Guidance

Hightstown Junior and Senior High Schools, Hightstown, New Jersey

Mr. Melvin H. Kreps, Superintendent
Mr. Paul D. Haring, Principal, Senior High School
Mr. Frank Fucarino, Principal, Junior High School
Mr. H. C. Strayhorn, Director of Guidance

Neshaminy High School, Langhorne, Pennsylvania

Dr. Oliver Heckman, Superintendent
Mr. John Stoops, Principal
Miss Georgiana Staehle, Guidance Counselor

Junior #3 School, Trenton, New Jersey

Miss Sarah C. Christie, Assistant Superintendent
Mr. William Walker, Principal

New Jersey School Development Council, Rutgers University, New Brunswick, New Jersey

Dr. Frank Sherer, Executive Secretary

Princeton High School, Princeton, New Jersey

Mr. B. Woodhull Davis, Superintendent
Mr. William H. Rhodes, Principal
Mr. Fred S. Coffman, Director of Guidance

Appendix B

APPENDIX B

Sample of the Announcement Sent Home to Parents

HIGHTSTOWN JUNIOR AND SENIOR HIGH SCHOOLS

HIGHTSTOWN, NEW JERSEY

May 13, 1960

Dear Parents,

The junior and senior high schools are cooperating with Mr. Richard E. Stafford, a doctoral candidate at Princeton University and a Psychometric Fellow at Educational Testing Service, in a study of similarities between students and their parents. The study depends upon the cooperation of 100 students and their parents. We have been given the opportunity of participating in this research program and, since we believe educational research to be necessary in our present day civilization, we sincerely urge you to cooperate in this study. This study has been approved by the Hightstown Board of Education and endorsed by the New Jersey School Development Council. Students must have passed their 13th birthday but not reached their 18th.

About two hours of testing time will be necessary and appointments for testing in groups of ten families or less will be made by Mr. Stafford. Parents and students will take the same tests (not intelligence or personality tests) at the same time. All test scores will be strictly confidential with the exception that the students' scores will be made available to the guidance department. Each family may request a report of their own test scores, if they wish.

Please check below a period when you (as a family group) can take this short battery of tests. As a convenience to Mr. Stafford, please record your address and telephone number.

Sincerely yours,

H. C. Strayhorn, Director of Guidance

Paul D. Haring, Principal, Senior High School

Frank Fucarino, Principal, Junior High School

Parents' Signatures_________________________ _________________________

Address____

Student's Signature_________________________ Telephone Number__________

Monday night____Wednesday night____Friday night____Saturday morning____

Other____________________________________

Please return this sheet on Monday, May 16, and in any case no later than May 20th, to the Guidance Department of the Senior High School or Mr. Fucarino's office.

Appendix C

APPENDIX C

Administrator's Manual for the Family Test Battery

General Instructions

1. Materials and Equipment

Complete sets of the eight tests should be on hand for the number of subjects taking the tests at that session, plus extra sets of the battery in case of defective tests. Two pencils should also be provided for each person with additional pencils allowed for breakage or wear. Separate answer sheets are not used.

Two stop watches will be used to time all tests which have exact time limits, one watch will time all other tests as a check against estimated times. Each stop watch will be checked against the other for accuracy.

2. Distribution of Materials

A full set of tests plus a questionnaire will be in each envelope. All tests and envelopes will be marked with a serial number for that family, followed by a "-1" for fathers, "-2" for mothers, "-3" for sons, "-4" for daughters, "-5" for second son, and "-6" for second daughter. Envelopes will be grouped together and will be handed to the father to be distributed to other members of the family.

3. Testing Schedule

Times listed below do not include a five-minute break nor the five minutes allotted for handing out the tests. The tests to be administered and times allotted are as follows:

	Time Allotted				
Test	Admin.		Testing		
Questionnaire	1		5		
Symbol Comparison Test	2		5*		
Word Association Test	3		7		
Mental Arithmetic Test	1		9*		
Pitch Discrimination Test	3	(break)	7		
Letter Concepts Test	3		8*		
Spelling Test	1		6		
Identical Blocks Test	3		8*		
English Vocabulary Test	2		12		
Total Time	19	+	67	=	86
Discussion	15				

*Time must be exact, all others are approximate.

4. Supervision

All questions must be answered before a test is begun; no questions will be permitted after testing starts. During the working time on each test, the administrator and proctors should be alert to give assistance in case of defective tests, broken pencils, etc. In case anyone misses the instructions, he should be told to wait until after the test battery has been given, then he may take the test over if he wishes. Since several of the tests are to be accurately timed, it is important to see that everyone is working on the correct test.

SPECIFIC TESTING DIRECTIONS

In some cases, test directions may be given orally by the administrator. In others, they are read silently by the examinees, or both. Times for directions, although specifically given, are not fixed; therefore, if anyone needs slightly more or less time to understand directions and study the sample problems, the administrator is free to adjust the instruction times accordingly. For those tests marked with an asterisk on the first page, however, times must be adhered to strictly by stop watch.

When the majority of examinees are seated, and the testing envelopes distributed, the following should be read.

> Good evening. Tonight you are going to take a few experimental tests of quite a varied nature. These are not IQ tests, and, for the most part, they do not require prior knowledge, although one or two of them may recall your school days. Although both parents and their sons and daughters are taking the same tests, each will be scored according to his or her own age group. About halfway through the tests we will have a short break, and, at the conclusion of the tests, I will briefly summarize what the tests are supposed to be measuring and why this study is being done. Until then, I would appreciate it if you confine your questions to the instructions for taking these tests, but please ask questions about what to do on a test before starting to work on it.
>
> Now, please open your envelopes and take out the tests. You will notice that first is a questionnaire. Please do NOT look at any of the tests until I ask you to do so. Fill in the questionnaire, and, if there are any questions about it, I will be glad to answer them.

Allow about 5 minutes for filling in questionnaires, and as late-comers enter give them the envelopes and have them start filling in the questionnaires. As soon as all examinees have arrived start the testing by saying:

3

In order to finish in two hours, we will have to begin our tests. Those of you who have completed your questionnaires may put them back into the envelopes and, as each test is finished, place it in the envelope to keep your desk clear for working. If you have not completed the questionnaire, place it on the bottom of your tests and you will be given time later to finish it.

Pause

Now, please take the first test, the SYMBOL COMPARISON TEST, and fill in your sex and age in the upper right-hand corner. I will read the directions with you.

For each item in this test you are to compare two sets of symbols. If the two sets of symbols are identical, that is, if the same symbols are used in the same order, mark the letter "S" for "same" on the line between the two sets of symbols. If the two sets are different in any way, mark the letter "X" for "different." Note the following examples:

(a)	#$%&"*	X	#$%@"*
(b)	$%(?@+	X	$%(@?+
(c)	&%$#Z/	S	&%$#Z/

Item (a) has been marked "X" (different) because the fourth symbol in the second set has been changed from & to @.

Item (b) has been marked "X" (different) because the fourth and fifth symbols in the second set have been interchanged.

In item (c), the two sets of symbols are exactly identical and in indentical order so it has been marked "S" for "same."

Pause

On the next two pages you will find 100 pairs of symbol sets. Compare them as quickly as you can, marking those that are exactly alike with an "S" and those that are different in some way with an "X". Do not skip any items. Do them in the order in which they are numbered.

You will have exactly 5 minutes to do as many pairs as you can. At the end of 2 1/2 minutes, you will be asked to mark your place, and go right on working. Simply draw a line under the item on which you are working and go right on working. Remember this is primarily a test of speed, so it is better to get one or two wrong and get a lot done than it is to go slow and get them all correct. Are there any questions? (Pause) Ready? Turn the page and start.

Start stop watches. After 2 1/2 minutes say:

Draw a line to mark your place; keep right on working.

After 5 minutes say:

Stop. Place the test in your envelope and take your second test, the WORD ASSOCIATION TEST.

Please write your age and sex in the upper right-hand corner. In this test, you will hear a list of words. As a word is read to you, you are to write down the very first word that comes to your mind. It doesn't matter how crazy or common the ~~word is,~~ you should write down the very first word that comes to you after the stimulus word is heard. For example, if I said "cake," you might write down "icing."

Now these words are going to be read rather quickly so you must write them down as fast as you can. To help you keep your place, put a question mark if you do not understand the word read. If you hear the word that is read but just cannot get a word in response, place a dash on the line. In addition, the 26th, 51st, and 76th items will be announced to make sure we are together. Are there any questions? (Pause) Here is the first word.

Read words. After the list is finished say:

Please place the test in your envelope and take the next test, the MENTAL ARITHMETIC TEST. Please write your sex and age in the upper right-hand corner. I will read the directions over with you.

Here are some problems in arithmetic. Most of them can be solved in your head (that's a lie!), but if you need to figure, please do it right in this booklet. Below each problem are seven answers, only one of which is the correct answer. Circle the correct answer as in the example below:

I. How many pencils can you buy for 50 cents at the rate of 2 for 5 cents?

5 10 [✓ 20] 25 100 125 250

The number 20 is circled because 50 cents is 10 times 5 cents, therefore 10 times 2 is twenty.

You will have exactly 9 minutes to do the 20 problems, so if you get stuck on a problem, skip it, and come back to it later if you have time. Are there any questions? (Pause) All right, turn the page and begin.

Start stop watches. After 9 minutes say:

Stop! Please put this test in your envelope and take the next test, the PITCH DISCRIMINATION TEST. Please fill in the upper right-hand corner. (Pause)

In this test, you are going to hear two notes, like this (whistle two notes). The second note may be higher, lower, or the same. If the second note is lower than the first you will write "L" for lower, if the second note is higher than the first, you will write "H" for higher, and if the second note is the same as the first, you will write "S" for same.

At the top of your page you will see three boxes labeled "Practice." You are going to hear three pairs of practice notes and, after each pair, write in the box the letter indicating whether the second note was higher, lower, or the same.

Play tape for three practice notes. Then say:

You should have "H", "S", and "L." You will notice the numbers go across the page. Remember, the notes will get very close together but mark each box with either H, L, or S. Are there any questions?

Play tape, after it is finished say:

Please put this test into your envelope, and now we will take a 5-minute break.

FIVE-MINUTE BREAK

After five minutes or so, urge people back to their seats; when they are all assembled, say:

Please take your next test, the LETTER CONCEPTS TEST, and, after you fill in the upper right-hand corner, I will read the directions with you.

In this test two pairs of letter patterns are given at the beginning of each item in two rows, marked "Given" and "and" as in Examples I and II below. The pattern on the left in each row is related to the pattern on the right in the same way for each pair; in other words, the two pairs of letter patterns are illustrations of the same rule. Your task is to discover this rule and apply it to the third row of letter patterns, marked "Then."

For each item in the test you must decide which of the five choices is related to the letter pattern in the row beside "Then" according to the rule illustrated in the first two rows. When you find the correct solution, circle it.

Example I

Given BCD : DCB
and FGH : HGF
Then JKL : LJK JLK KJL KLJ [✓ LKJ]

LKJ is circled as the correct choice because the rule illustrated in the first two rows is "reverse the letters." The next example is more difficult.

Example II

Given ORTJ : JTRA
and TGRC : CRGL
Then IKBD : OKBD KBDZ IBDK [✓ DBKZ] BKDZ

DBKZ is circled as the correct choice because the rule illustrated in the first two rows is "omit the first letter and reverse the last three, adding a new letter on the end." (Pause)

One explanation; none of these items depends upon alphabetical arrangements! If you get stuck on any item, skip it and come back to it, if there is time. You will have exactly 8 minutes for 14 problems. Accuracy counts. Any questions? Ready? Turn the page and start!

After 8 minutes say:

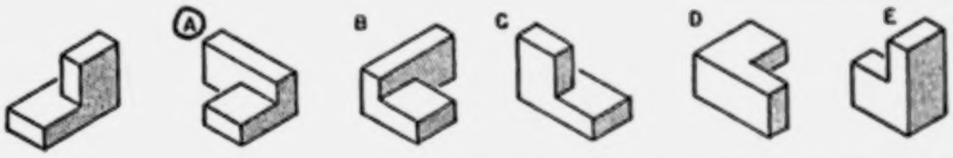
STOP! Please place the test in your envelope and take the next test, the SPELLING TEST. In this test, I am going to read to you a list of words and ask you to print each word on the sheet before you. After reading each word I will put it into a phrase to give you the part of speech and context in which it is used. Try to spell each word, even though you guess. (Pause) Are there any questions? I will repeat any word at the end.

Read words.

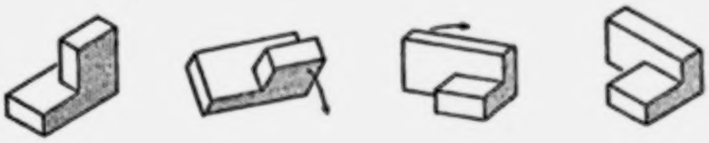
Does anyone wish a word repeated? (Pause)

Please put the test in your envelope and take the IDENTICAL BLOCKS TEST. Please fill in the upper right-hand section. (Pause). Let me read these directions over with you. This test is made up of pictures of blocks of various shapes. The block at the left is the reference block and the five blocks to the right are the answer blocks. One of these five blocks is the same as the reference block, but it is seen from a different point of view, that is, it is a rotation of the reference block. The other four blocks could not be obtained by rotation. You are to circle the letter just above the block which is the same as the reference block. For example:

I.

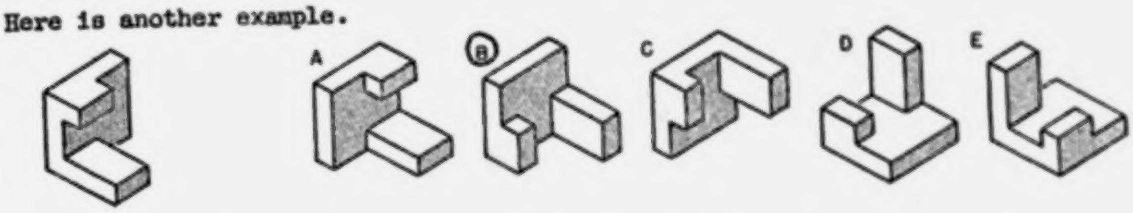


Block "A" has the same shape as the reference block, but it has been turned as shown in the figure below.

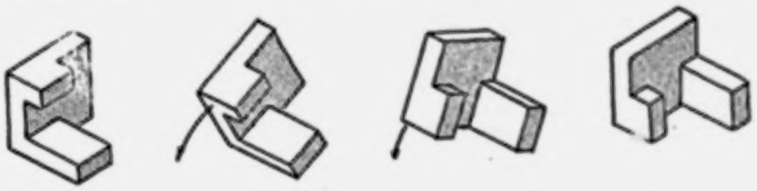


Here is another example.

II.



The illustration below shows that "B" is the correct answer.



In the following items, circle the letter of the block which you think is the same as the reference block. If you get stuck on any item, skip it and come back to it later, if there is time. The shading is there only to help you see the blocks in three dimensions. It does not enter into the problem. You will have exactly 8 minutes to do 18 problems in this test. Are there any questions? (Pause) Ready? Turn the page and start!

After 8 minutes say:

Stop! Please put the test into your envelope and take the ENGLISH VOCABULARY TEST. Fill in the upper right-hand corner. (Pause) Let me read the directions over with you. In each of the following items you will find a word at the left, which is underlined, and five words to the right as in the sample item below. Read the underlined word at the left and try to find among the five words at the right the one which is closest in meaning. Read all five choices carefully and circle only the one which you feel is closest in meaning. (It will not necessarily be a synonym.) If you have never seen the underlined word before or are unsure of its meaning, do not guess but circle the question mark at the extreme right. For example:

I. a gate   animal   runner   window   [✓ door]   hole   ?

"Door" is circled because it is more like a gate than either a window or a hole, and certainly is neither an animal nor a runner.

Once in a while you may find that although you know some of the choices on the right are not the correct ones, you cannot narrow your choice down to one. In this case, you may cross out the choices that you are sure are not the correct ones. Be careful in crossing out words because if you cross out a correct word, you will lose credit just as you will if you circle the wrong word. Since you neither lose nor gain credit by circling the question mark, when you have any doubt, do so, and do not guess!

Although there is no time limit for this test, you will work more accurately if you work briskly. There are 48 items so make sure that you have an answer for each item either by circling the correct word or the question mark, or by crossing out words which are incorrect. Are there any questions? (Pause) Begin as soon as you understand the instructions.

After 12 minutes (or when most people appear to be finished) say:

Those of you who are finished may put your test in the envelope. If you are not finished, lay your paper to one side. I am going to tell you very briefly what this study is about and what some of these tests are trying to measure.

Give a short talk on the objectives of this research.

If there are any of you who have not finished the questionnaire or the vocabulary test, I hope you can stay and finish them. I want to thank you for your cooperation. The results will be mailed to you, if you have so requested.

APPENDIX D

Fathers + Sons (N = 51)

$q_{\sigma}^{2} = .098$

3 3.4 0.4	43 42.6 0.4
2 1.6 0.4	3 3.4 0.4

$\chi^2 = .198$

$q_{\sigma}^{2} = .196$

7 5.6 1.4	34 35.4 1.4
3 4.4 1.4	7 5.6 1.4

$\chi^2 = 1.201$

$q_{\sigma}^{2} = .294$

10 6.9 3.1	26 28.7 2.7
5 8.5 3.5	10 6.9 3.1

$\chi^2 = 4.302$

$q_{\sigma}^{2} = .392$

9 7.5 1.5	22 23.5 1.5
11 12.5 1.5	9 7.5 1.5

$\chi^2 = .876$

$q_{\sigma}^{2} = .490$

12 7.5 4.5	14 18.5 4.5
13 17.5 4.5	12 7.5 4.5

$\chi^2 = 7.652$

$q_{\sigma}^{2} = .588$

11 7.0 4.0	10 14.0 4.0
19 23.0 4.0	11 7.0 4.0

$\chi^2 = 6.410$

$q_{\sigma}^{2} = .686$

9 6.0 3.0	7 10.0 3.0
26 29.0 3.0	9 6.0 3.0

$\chi^2 = 4.210$

$q_{\sigma}^{2} = .745$

8 5.2 2.8	5 7.8 2.8
30 32.8 2.8	8 5.2 2.8

$\chi^2 = 4.260$

$q_{\sigma}^{2} = .804$

7 4.2 2.8	3 5.8 2.8
34 36.8 2.8	7 4.2 2.8

$\chi^2 = 5.298$

$q_{\sigma}^{2} = .902$

4 2.3 1.7	1 2.7 1.7
42 43.7 1.7	4 2.3 1.7

$\chi^2 = 3.650$

$q_{\sigma}^{2} =$

$\chi^2 =$

$q_{\sigma}^{2} =$

$\chi^2 =$

Mothers + Daughters (N = 63)

$q_{\sigma}^{2} = .095$

5 4.2 .8	52 52.9 .9
1 1.8 .8	5 4.2 .8

$\chi^2 = .676$

$q_{\sigma}^{2} = .190$

8 6.7 1.3	43 44.3 1.3
4 5.2 1.2	8 6.7 1.3

$\chi^2 = .819$

$q_{\sigma}^{2} = .302$

11 8.6 2.4	33 35.4 2.4
8 10.5 2.5	11 8.6 2.4

$\chi^2 = 2.097$

$q_{\sigma}^{2} = .397$

10 9.3 .7	28 28.7 .7
15 15.8 .8	10 9.3 .7

$\chi^2 = .163$

$q_{\sigma}^{2} = .508$

15 9.2 5.8	16 21.8 5.8
17 22.8 5.8	15 9.2 5.8

$\chi^2 = 10.332$

$q_{\sigma}^{2} = .603$

16 8.9 7.6	9 16.6 7.6
22 29.5 7.5	16 8.4 7.6

$\chi^2 = 19.139$

$q_{\sigma}^{2} = .714$

14 7.0 7	4 11.0 7
31 38.0 7	14 7.0 7

$\chi^2 = 19.744$

$q_{\sigma}^{2} = .810$

9 5.1 3.9	3 6.9 3.9
42 45.9 3.9	9 5.1 3.9

$\chi^2 = 8.500$

$q_{\sigma}^{2} = .905$

5 2.8 2.2	1 3.2 2.2
52 54.2 2.2	3 2.8 2.2

$\chi^2 = 5.059$

$q_{\sigma}^{2} =$

$\chi^2 =$

$q_{\sigma}^{2} =$

$\chi^2 =$

$q_{\sigma}^{2} =$

$\chi^2 =$

FIG. D-1. SYMBOL COMPARISON TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (Low Score = Recessive)

Fathers + Sons (N = 51)

q^2_σ = .902

5 2.3 .7	43 43.7 .7
2 2.7 .7	3 2.3 .7

χ^2 = .619

q^2_σ = .804

7 4.2 2.8	34 36.8 2.8
3 5.8 2.8	7 4.2 2.8

χ^2 = 5.298

q^2_σ = .706

10 5.8 4.2	26 30.2 4.2
5 9.2 4.2	10 5.8 4.2

χ^2 = 8.584

q^2_σ = .608

9 6.8 2.2	22 24.2 2.2
11 13.2 2.2	9 6.8 2.2

χ^2 = 1.990

q^2_σ = .510

12 7.4 4.6	14 18.6 4.6
13 17.5 4.5	12 7.4 4.6

χ^2 = 8.014

q^2_σ = .412

11 7.5 3.5	10 13.5 3.5
19 22.5 3.5	11 7.5 3.5

χ^2 = 4.719

q^2_σ = .314

9 7 2	7 9 2
26 28 2	9 7 2

χ^2 = 1.730

q^2_σ = .255

8 6.4 1.6	5 6.6 1.6
30 31.6 1.6	8 6.4 1.6

χ^2 = 1.269

q^2_σ = .196

7 5.6 1.4	3 4.4 1.4
34 35.4 1.4	7 5.6 1.4

χ^2 = 1.201

q^2_σ = .098

4 3.4 .6	1 1.6 .6
42 42.6 .6	4 3.4 .6

χ^2 = .445

q^2_σ =

χ^2 =

q^2_σ =

χ^2 =

Mothers + Daughters (N = 63)

q^2_σ = .905

5 2.8 2.2	52 54.2 2.2
1 3.2 2.2	5 2.8 2.2

χ^2 = 5.059

q^2_σ = .810

8 5.1 2.9	43 45.9 2.9
4 6.9 2.9	8 5.1 2.9

χ^2 = 4.700

q^2_σ = .698

11 7.3 3.7	33 36.7 3.7
8 11.7 3.7	11 7.3 3.7

χ^2 = 5.294

q^2_σ = .603

10 8.4 1.6	28 29.5 1.5
15 16.6 1.6	10 8.4 1.6

χ^2 = .840

q^2_σ = .498

15 9.3 5.7	16 21.7 5.7
17 22.7 5.7	15 9.3 5.7

χ^2 = 9.916

q^2_σ = .397

16 9.3 6.7	9 15.8 6.8
22 28.7 6.7	16 9.3 6.7

χ^2 = 14.144

q^2_σ = .286

14 8.4 5.6	4 9.6 5.6
31 36.6 5.6	14 8.4 5.6

χ^2 = 11.590

q^2_σ = .191

9 6.8 2.2	3 5.2 2.2
42 44.2 2.2	9 6.8 2.2

χ^2 = 2.464

q^2_σ = .095

5 4.2 .8	1 1.8 .8
52 52.9 .9	5 4.2 .8

χ^2 = .676

q^2_σ =

χ^2 =

q^2_σ =

χ^2 =

q^2_σ =

χ^2 =

FIG. D-2. SYMBOL COMPARISON TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (High Score = Recessive)

Fathers + Sons (N = 51)

q^2 = .098

3 3.4 .4	43 42.6 .4
2 1.6 .4	3 3.4 .4

X^2 = .198

q^2 = .196

6 5.6 .4	35 35.4 .4
4 4.4 .4	6 5.6 .4

X^2 = .098

q^2 = .294

8 6.9 1.1	28 29.1 1.1
7 8.1 1.1	8 6.9 1.1

X^2 = .545

q^2 = .392

10 7.5 2.5	21 23.5 2.5
10 12.5 2.5	10 7.5 2.5

X^2 = 2.433

q^2 = .490

13 7.5 5.5	13 18.5 5.5
12 17.5 5.5	13 7.5 5.5

X^2 = 11.430

q^2 = .588

14 7.0 7	7 14.0 7
16 23.0 7	14 7.0 7

X^2 = 19.630

q^2 = .686

12 6.0 6	4 10.0 6
23 29.0 6	12 6.0 6

X^2 = 16.841

q^2 = .804

10 4.2 5.8	0 5.8 5.8
31 36.8 5.8	10 4.2 5.8

X^2 = 22.733

q^2 = .902

5 2.3 2.7	0 2.7 2.7
41 43.7 2.7	5 2.3 2.7

X^2 = 9.206

q^2 =

X^2 =

q^2 =

X^2 =

q^2 =

X^2 =

Mothers + Daughters (N = 63)

q^2 = .095

5 4.2 .8	52 52.9 .9
1 1.8 .8	5 4.2 .8

X^2 = .676

q^2 = .190

10 6.7 3.3	41 44.3 3.3
2 5.2 3.2	10 6.7 3.3

X^2 = 5.466

q^2 = .302

13 8.6 4.4	31 35.4 4.4
6 10.5 4.5	13 8.6 4.4

X^2 = 6.978

q^2 = .397

16 9.3 6.7	22 28.7 6.7
9 15.8 6.8	16 9.3 6.7

X^2 = 14.144

q^2 = .508

14 9.2 4.8	17 21.8 4.8
18 22.8 4	14 9.2 4.8

X^2 = 7.076

q^2 = .603

15 8.5 6.5	10 16.5 6.5
23 29.5 6.5	15 8.5 6.5

X^2 = 13.934

q^2 = .714

11 7.0 4	7 11.0 4
34 38.0 4	11 7.0 4

X^2 = 6.447

q^2 = .809

11 5.2 5.8	1 6.9 5.9
40 45.8 5.8	11 5.2 5.8

X^2 = 18.718

q^2 = .905

6 2.8 3.2	0 3.2 3.2
51 54.2 3.2	6 2.8 3.2

X^2 = 10.703

q^2 =

X^2 =

q^2 =

X^2 =

q^2 =

X^2 =

FIG. D-3. WORD ASSOCIATION TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (Low Score = Recessive)

Fathers + Sons (N = 51)

$q^2 = .902$

3 2.3 .7	43 43.7 .7
2 2.7 .7	3 2.3 .7

$X^2 = .619$

$q^2 = .804$

6 4.2 1.8	35 36.8 1.8
4 5.8 1.8	6 4.2 1.8

$X^2 = 2.189$

$q^2 = .706$

8 5.8 2.2	28 30.2 2.2
7 9.2 2.2	8 5.8 2.2

$X^2 = 2.355$

$q^2 = .608$

10 6.8 3.2	21 24.2 3.2
10 13.2 3.2	10 6.8 3.2

$X^2 = 4.210$

$q^2 = .510$

13 7.4 5.6	13 18.6 5.6
12 17.5 5.5	13 7.4 5.6

$X^2 = 11.890$

$q^2 = .412$

14 7.5 6.5	7 13.5 6.5
16 22.5 6.5	14 7.5 6.5

$X^2 = 16.274$

$q^2 = .314$

12 7 5	4 9 5
23 27.9 4.9	12 7 5

$X^2 = 10.781$

$q^2 = .196$

10 5.6 4.4	0 4.4 4.4
31 35.4 4.4	10 5.6 4.4

$X^2 = 11.861$

$q^2 = .098$

5 3.4 1.6	0 1.6 1.6
41 42.6 1.6	5 3.4 1.6

$X^2 = 3.166$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Daughters (N = 63)

$q^2 = .905$

5 2.8 2.2	52 54.2 2.2
1 3.2 2.2	5 2.8 2.2

$X^2 = 5.059$

$q^2 = .810$

10 5.1 4.9	41 45.9 4.9
2 6.9 4.9	10 5.1 4.9

$X^2 = 13.418$

$q^2 = .698$

13 7.2 5.8	31 36.8 5.8
6 11.8 5.8	13 7.2 5.8

$X^2 = 13.109$

$q^2 = .603$

16 8.4 7.6	22 29.5 7.5
9 16.6 7.6	16 8.4 7.6

$X^2 = 19.139$

$q^2 = .492$

14 9.2 4.8	17 21.8 4.8
18 22.8 4.8	14 9.2 4.8

$X^2 = 7.076$

q^2 .397

15 9.3 5.7	10 15.8 5.8
23 28.7 5.7	15 9.3 5.7

$X^2 = 10.248$

$q^2 = .286$

11 8.4 2.6	7 9.6 2.6
34 36.6 2.6	11 8.4 2.6

$X^2 = 2.498$

$q^2 = .191$

11 6.8 4.2	1 5.2 4.2
40 44.2 4.2	11 6.8 4.2

$X^2 = 8.980$

$q^2 = .095$

6 4.1 1.9	0 1.9 1.9
51 52.9 1.9	6 4.1 1.9

$X^2 = 3.729$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

FIG. D-4. WORD ASSOCIATION TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (High Score = Recessive)

Fathers + Daughters (N = 62)

$q^2 = .067$

14 11.8 2.2	2 4.2 2.2
44 46.0 2	2 0 2

$X^2 = 1.65$

$q^2 = .104$

17 13.6 3.4	3 6.4 3.4
39 42.0 3	3 0 3

$X^2 = 2.87$

$q^2 = .176$

21 15.1 5.9	5 10.9 5.9
30 36.0 6	6 0 6

$X^2 = 6.50$

$q^2 = .250$

23 15.5 7.5	8 15.5 7.5
23 31.0 8	8 0 8

$X^2 = 9.32$

$q^2 = .338$

22 15.1 6.9	14 21.0 7
19 26.0 7	7 0 7

$X^2 = 7.37$

$q^2 = .437$

22 13.9 8.1	19 27.1 8.1
13 21.0 8	8 0 8

$X^2 = 10.19$

$q^2 = .527$

20 12.3 7.7	25 32.7 7.7
9 17.0 8	8 0 8

$X^2 = 10.40$

$q^2 = .650$

17 9.7 7.3	33 40.3 7.3
5 12.0 7	7 0 7

$X^2 = 10.90$

$q^2 = .759$

13 6.9 6.1	41 47.1 6.1
2 8.0 6	6 0 6

$X^2 = 10.68$

$q^2 = .874$

8 3.8 4.2	50 54.2 4.2
0 4.0 4	4 0 4

$X^2 = 8.97$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Sons (N = 50)

$q^2 = .080$

0 0 0	4 4.0 0
36 35.9 .1	10 10.2 .2

$X^2 = .004$

$q^2 = .120$

1 0 1	5 6.0 1
32 32.7 .7	12 11.3 .7

$X^2 = .22$

$q^2 = .180$

0 0 0	9 9.0 0
29 28.8 .2	12 12.2 .2

$X^2 = .005$

$q^2 = .260$

1 0 1	12 13.0 1
24 24.5 .5	13 12.5 .5

$X^2 = .11$

$q^2 = .360$

3 0 3	15 18.0 3
17 20.0 3	15 12.0 3

$X^2 = 1.70$

$q^2 = .460$

4 0 4	19 23.0 4
12 16.1 4.1	15 10.9 4.1

$X^2 = 3.28$

$q^2 = .580$

4 0 4	25 29.0 4
8 11.9 3.9	13 9.1 3.9

$X^2 = 3.50$

$q^2 = .700$

6 0 6	29 35.0 6
2 8.2 6.2	13 6.9 6.1

$X^2 = 11.11$

$q^2 = .840$

3 0 3	39 42.0 3
1 4.2 3.2	7 3.8 3.2

$X^2 = 5.35$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

FIG. D-5. MENTAL ARITHMETIC TEST. Hypothetical Dichotomies and Pseudo Chi-square Tests of Goodness of Fit (High Score = Sex-linked Recessive)

Fathers + Sons (N = 51)

$q^2 = .098$

3 3.4 .4	43 42.6 .4
2 1.6 .4	3 3.4 .4

$X^2 = .198$

$q^2 = .196$

6 5.6 .4	35 35.4 .4
4 4.4 .4	6 5.6 .4

$X^2 = .098$

$q^2 = .294$

8 6.9 1.1	28 29.1 1.1
7 8.1 1.1	8 6.9 1.1

$X^2 = .542$

$q^2 = .392$

11 7.5 3.5	20 23.5 3.5
9 12.5 3.5	11 7.5 3.5

$X^2 = 4.768$

$q^2 = .490$

11 7.5 3.5	15 18.5 3.5
14 17.5 3.5	11 7.5 3.5

$X^2 = 4.629$

$q^2 = .588$

9 7 2	12 14 2
21 23.0 2	9 7 2

$X^2 = 1.602$

$q^2 = .686$

7 6 1	9 10 1
28 29 1	7 6 1

$X^2 = .468$

$q^2 = .784$

6 4.6 1.4	5 6.4 1.4
34 35.3 1.3	6 4.6 1.4

$X^2 = 1.206$

$q^2 = .843$

4 3.5 .5	4 4.5 .5
39 39.5 .5	4 3.5 .5

$X^2 = .205$

$q^2 = .902$

3 2.3 .7	2 2.7 .7
43 43.7 .7	3 2.3 .7

$X^2 = .619$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Daughters (N = 63)

$q^2 = .095$

3 4.2 1.2	54 52.9 1.1
3 1.8 1.2	3 4.2 1.2

$X^2 = 1.509$

$q^2 = .190$

9 6.7 2.3	42 44.3 2.3
3 5.2 2.2	9 6.7 2.3

$X^2 = 2.629$

$q^2 = .286$

15 8.4 6.6	30 36.6 6.6
3 9.6 6.6	15 8.4 6.6

$X^2 = 16.099$

$q^2 = .397$

13 9.3 3.7	25 28.7 3.7
12 15.8 3.8	13 9.3 3.7

$X^2 = 4.335$

$q^2 = .492$

15 9.3 5.7	17 22.7 5.7
16 21.7 5.7	15 9.3 5.7

$X^2 = 9.916$

$q^2 = .603$

13 8.4 4.6	12 16.6 4.6
25 29.5 4.5	13 8.4 4.6

$X^2 = 6.999$

$q^2 = .714$

11 7 4	7 11 4
34 38 4	11 7 4

$X^2 = 6.447$

$q^2 = .762$

9 6.1 2.9	6 8.9 2.9
39 41.9 2.9	9 6.1 2.9

$X^2 = 3.903$

$q^2 = .810$

7 5.1 1.9	5 6.9 1.9
44 45.9 1.9	7 5.1 1.9

$X^2 = 2.018$

$q^2 = .857$

7 4 3	2 5 3
47 50 3	7 4 3

$X^2 = 6.480$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

FIG. D-6. PITCH DISCRIMINATION TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (Low Score = Recessive)

Fathers + Sons (N = 51)

$q^2 = .902$

3 2.3 .7	43 43.7 .7
2 2.7 .7	3 2.3 .7

$X^2 = .619$

$q^2 = .804$

6 4.2 1.8	35 36.8 1.8
4 5.8 1.8	6 4.2 1.8

$X^2 = 2.190$

$q^2 = .706$

8 5.8 2.2	28 30.2 2.2
7 9.2 2.2	8 5.8 2.2

$X^2 = 2.355$

$q^2 = .608$

11 6.8 4.2	20 24.2 4.2
9 13.2 4.2	11 6.8 4.2

$X^2 = 7.254$

$q^2 = .510$

11 7.4 3.6	15 18.6 3.6
14 17.5 3.5	11 7.4 3.6

$X^2 = 4.899$

$q^2 = .412$

9 7.5 1.5	12 13.5 1.5
21 22.5 1.5	9 7.5 1.5

$X^2 = .867$

$q^2 = .314$

7 7 0	9 9 0
28 28 0	7 7 0

$X^2 = 0$

$q^2 = .216$

6 5.9 .1	5 5.2 .2
34 34.1 .1	6 5.9 .1

$X^2 = .011$

$q^2 = .157$

4 4.8 .8	4 3.2 .8
39 38.1 .9	4 4.8 .8

$X^2 = .488$

$q^2 = .098$

3 3.4 .4	2 1.6 .4
43 42.6 .4	3 3.4 .4

$X^2 = .198$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Daughters (N = 63)

$q^2 = .905$

3 2.8 .2	54 54.2 .2
3 3.2 .2	3 2.8 .2

$X^2 = .042$

$q^2 = .810$

9 5.1 3.9	42 45.9 3.9
3 6.9 3.9	9 5.1 3.9

$X^2 = 8.500$

$q^2 = .714$

15 7 8	30 38 8
3 11 8	15 7 8

$X^2 = 25.788$

$q^2 = .603$

13 8.4 4.6	25 29.5 4.5
12 16.6 4.6	13 8.4 4.6

$X^2 = 6.999$

$q^2 = .508$

15 9.2 5.8	17 22.8 5.8
16 21.8 5.8	15 9.2 5.8

$X^2 = 10.332$

$q^2 = .397$

13 9.3 3.7	12 15.8 3.8
25 28.7 3.7	13 9.3 3.7

$X^2 = 4.335$

$q^2 = .286$

11 8.4 2.6	7 9.6 2.6
34 36.6 2.6	11 8.4 2.6

$X^2 = 2.498$

$q^2 = .238$

9 7.7 1.3	6 7.3 1.3
39 40.3 1.3	9 7.7 1.3

$X^2 = .712$

$q^2 = .191$

7 6.8 .2	5 5.2 .2
44 44.2 .2	7 6.8 .2

$X^2 = .020$

$q^2 = .143$

7 5.6 1.4	2 3.4 1.4
47 48.4 1.4	7 5.6 1.4

$X^2 = 1.317$

$q^2 = .095$

4 4.2 .2	2 1.8 .2
53 52.9 .1	4 4.2 .2

$X^2 = .041$

$q^2 =$

$X^2 =$

FIG. D-7. PITCH DISCRIMINATION TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (High Score = Recessive)

Fathers + Sons (N = 51)

σ^2 = .098

3 3.4 .4	43 42.6 .4
2 1.6 .4	3 3.4 .4

X^2 = .198

σ^2 = .196

7 5.6 1.4	34 35.4 1.4
3 4.4 1.4	7 5.6 1.4

X^2 = 1.201

σ^2 = .294

10 6.9 3.1	26 29.1 3.1
5 8.1 3.1	10 6.9 3.1

X^2 = 4.302

σ^2 = .412

12 7.5 4.5	18 22.5 4.5
9 13.5 4.5	12 7.5 4.5

X^2 = 7.800

σ^2 = .510

12 7.4 4.6	13 17.5 4.5
14 18.6 4.6	12 7.4 4.6

X^2 = 8.014

σ^2 = .608

14 6.8 7.2	6 13.2 7.2
17 24.2 7.2	14 6.8 7.2

X^2 = 21.316

σ^2 = .706

10 5.8 4.2	5 9.2 4.2
26 30.2 4.2	10 5.8 4.2

X^2 = 8.584

σ^2 = .804

9 4.2 4.8	1 5.8 4.8
32 36.8 4.8	9 4.2 4.8

X^2 = 15.570

σ^2 = .902

4 2.3 1.7	1 2.7 1.7
42 43.7 1.7	4 2.3 1.7

X^2 = 3.650

σ^2 =

X^2 =

σ^2 =

X^2 =

σ^2 =

X^2 =

Mothers + Daughters (N = 63)

σ^2 = .095

6 4.2 1.8	51 52.9 1.9
0 1.8 1.8	6 4.2 1.8

X^2 = 3.411

σ^2 = .190

8 6.7 1.3	43 44.3 1.3
4 5.2 1.2	8 6.7 1.3

X^2 = .820

σ^2 = .286

10 8.4 1.6	35 36.6 1.6
8 9.6 1.6	10 8.4 1.6

X^2 = .946

σ^2 = .397

11 9.3 1.7	27 28.7 1.7
14 15.8 1.8	11 9.3 1.7

X^2 = .927

σ^2 = .492

10 9.3 .7	22 22.7 .7
21 21.7 .7	10 9.3 .7

X^2 = .150

σ^2 = .603

10 8.5 1.5	15 16.5 1.5
28 29.5 1.5	10 8.5 1.5

X^2 = .742

σ^2 = .698

10 7.2 2.8	9 11.8 2.8
34 36.7 2.7	10 7.2 2.8

X^2 = 3.041

σ^2 = .810

9 5.1 3.9	3 6.9 3.9
42 45.9 3.9	9 5.1 3.9

X^2 = 8.500

σ^2 = .905

6 2.8 3.2	0 3.2 3.2
51 54.2 3.2	6 2.8 3.2

X^2 = 10.703

σ^2 =

X^2 =

σ^2 =

X^2 =

σ^2 =

X^2 =

FIG. D-8. LETTER CONCEPTS TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (Low Score = Recessive)

Fathers + Sons (N = 51)

$q^2 = .902$

3 2.3 .7	43 43.7 .7
2 2.7 .7	3 2.3 .7

$X^2 = .619$

$q^2 = .804$

7 4.2 2.8	34 36.8 2.8
3 5.8 2.8	7 4.2 2.8

$X^2 = 5.298$

$q^2 = .706$

10 5.8 4.2	26 30.2 4.2
5 9.2 4.2	10 5.8 4.2

$X^2 = 8.584$

$q^2 = .588$

12 7 5	18 23 5
9 14 5	12 7 5

$X^2 = 10.015$

$q^2 = .490$

12 7.5 4.5	13 17.5 4.5
14 18.5 4.5	12 7.5 4.5

$X^2 = 7.651$

$q^2 = .392$

14 7.5 6.5	6 12.5 6.5
17 23.5 6.5	14 7.5 6.5

$X^2 = 16.444$

$q^2 = .294$

10 6.9 3.1	5 8.1 3.1
26 29.1 3.1	10 6.9 3.1

$X^2 = 4.302$

$q^2 = .196$

9 5.6 3.4	1 4.4 3.4
32 35.4 3.4	9 5.6 3.4

$X^2 = 7.082$

$q^2 = .098$

4 3.4 .6	1 1.6 .6
42 42.6 .6	4 3.4 .6

$X^2 = .445$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Daughters (N = 63)

$q^2 = .905$

6 2.8 3.2	51 54.2 3.2
0 3.2 3.2	6 2.8 3.2

$X^2 = 10.703$

$q^2 = .810$

8 5.1 2.9	43 45.9 2.9
4 6.9 2.9	8 5.1 2.9

$X^2 = 4.700$

$q^2 = .714$

10 7.0 3.0	35 38.0 3.0
8 11.0 3.0	10 7.0 3.0

$X^2 = 3.626$

$q^2 = .603$

11 8.4 2.6	27 29.5 2.5
14 16.6 2.6	11 8.4 2.6

$X^2 = 2.229$

$q^2 = .508$

10 9.2 .8	22 22.8 .8
21 21.8 .8	10 9.2 .8

$X^2 = .1965$

$q^2 = .397$

10 9.3 .7	15 15.8 .8
28 28.7 .7	10 9.3 .7

$X^2 = .1629$

$q^2 = .302$

10 8.6 1.4	9 10.4 1.4
34 35.4 1.4	10 8.6 1.4

$X^2 = .6996$

$q^2 = .190$

9 6.7 2.3	3 5.2 2.2
42 44.3 2.3	9 6.7 2.3

$X^2 = 2.629$

$q^2 = .095$

6 4.1 1.9	0 1.9 1.9
51 52.9 1.9	6 4.1 1.9

$X^2 = 3.729$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

FIG. D-9. LETTER CONCEPTS TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (High Score = Recessive)

Fathers + Daughters (N = 62)

$q^2 = .067$

1 0 1	45 46.0 1.0
3 4.2 1.2	13 11.8 1.2

$X^2 = .486$

$q^2 = .104$

2 0	40 42 2.0
4 6.4 2.4	16 13.6 2.4

$X^2 = 1.419$

$q^2 = .162$

6 0 6	31 37.0 6.0
4 10.1 6.1	21 14.9 6.1

$X^2 = 7.154$

$q^2 = .234$

8 0 8	24 32.0 8.0
7 14.5 7.5	23 15.5 7.5

$X^2 = 9.508$

$q^2 = .319$

7 0 7	20 27.0 7.0
13 19.8 6.8	22 15.2 6.8

$X^2 = 7.192$

$q^2 = .416$

10 0 10	12 22.0 10.0
16 25.8 9.8	24 14.2 9.8

$X^2 = 15.031$

$q^2 = .504$

11 0 11	7 18.0 11.0
20 31.2 11.2	24 12.8 11.2

$X^2 = 20.543$

$q^2 = .650$

11 0 11	1 12.0 11.0
29 40.3 11.3	21 9.7 11.3

$X^2 = 26.416$

$q^2 = .759$

7 0 7	1 8.0 7.0
40 47.1 7.1	14 6.9 7.1

$X^2 = 14.501$

$q^2 = .874$

4 0 4	0 4.0 4.0
50 54.2 4.2	8 3.8 4.2

$X^2 = 8.966$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Sons (N = 50)

$q^2 = .080$

12 10.2 1.8	34 35.9 1.9
2 4.0 2.0	2 0 2.0

$X^2 = 1.418$

$q^2 = .120$

14 11.3 2.7	30 32.7 2.7
3 6.0 3.0	3 0 3.0

$X^2 = 2.368$

$q^2 = .180$

16 12.2 3.8	25 28.8 3.8
5 9.0 4.0	4 0 4.0

$X^2 = 3.463$

$q^2 = .240$

18 12.5 5.5	20 25.6 5.6
6 12.0 6.0	6 0 6.0

$X^2 = 10.108$

$q^2 = .300$

18 12.4 5.6	17 22.6 5.6
9 15.0 6.0	6 0 6.0

$X^2 = 6.317$

$q^2 = .380$

17 11.8 5.2	14 19.2 5.2
14 19.0 5.0	5 0 5.0

$X^2 = 5.016$

$q^2 = .460$

16 10.9 5.1	11 16.1 5.1
18 23.0 5.0	5 0 5.0

$X^2 = 5.089$

$q^2 = .600$

13 8.8 4.2	7 11.3 4.2
26 30.0 4.0	4 0 4.0

$X^2 = 4.174$

$q^2 = .700$

12 6.9 5.1	3 8.2 5.2
30 35.0 5.0	5 0 5.0

$X^2 = 7.781$

$q^2 = .840$

7 3.9 3.1	1 4.2 3.2
39 42.0 3.0	3 0 3.0

$X^2 = 5.116$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

FIG. D-10. SPELLING TEST. Hypothetical Dichotomies and Pseudo Chi-square Tests of Goodness of Fit (Low Score = Sex-linked Recessive)

Fathers + Daughters (N = 62)

$q^2 = .067$

14 11.8 2.2	2 4.2 2.2
44 46.0 2.0	2 0 2.0

$X^2 = 1.650$

$q^2 = .115$

17 13.9 3.1	4 7.1 3.1
38 41.0 3.0	3 0 3.0

$X^2 = 2.264$

$q^2 = .162$

19 14.9 4.1	6 10.0 4.0
33 37.0 4.0	4 0 4.0

$X^2 = 3.161$

$q^2 = .250$

21 15.5 5.5	10 15.5 5.5
25 31.0 6.0	6 0 6.0

$X^2 = 5.065$

$q^2 = .338$

20 15.1 4.9	16 21.0 5.0
21 26.0 5.0	5 0 5.0

$X^2 = 3.742$

$q^2 = .416$

20 14.2 5.8	20 25.8 5.8
16 22.0 6.0	6 0 6.0

$X^2 = 5.309$

$q^2 = .504$

18 12.8 5.2	26 31.2 5.2
13 18.0 5.0	5 0 5.0

$X^2 = 4.368$

$q^2 = .624$

17 10.3 6.7	32 38.7 6.7
6 13.0 7.0	7 0 7.0

$X^2 = 9.287$

$q^2 = .759$

13 6.9 6.1	41 47.1 6.1
2 8.0 6.0	6 0 6.0

$X^2 = 10.683$

$q^2 = .874$

8 3.8 4.2	50 54.2 4.2
0 54.0 4.0	4 0 4.0

$X^2 = 8.968$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Sons (N = 50)

$q^2 = .080$

2 0 2.0	2 4.0 2.0
34 35.8 1.8	12 10.2 1.8

$X^2 = 1.408$

$q^2 = .120$

2 0 2.0	4 6.0 2.0
31 32.7 1.7	13 11.3 1.7

$X^2 = 1.011$

$q^2 = .180$

2 0 2.0	7 9.0 2.0
27 28.8 1.8	14 12.2 1.8

$X^2 = .823$

$q^2 = .260$

4 0 4.0	9 13.0 4.0
21 24.5 3.5	16 12.5 3.5

$X^2 = 2.711$

$q^2 = .340$

5 0 5.0	12 17.0 5.0
16 20.8 4.8	17 12.2 4.8

$X^2 = 4.467$

$q^2 = .440$

4 0 4.0	18 22.0 4.0
13 16.8 3.8	15 11.2 3.8

$X^2 = 2.876$

$q^2 = .560$

4 0 4.0	24 28.0 4.0
9 12.6 3.6	13 9.4 3.6

$X^2 = 2.979$

$q^2 = .700$

6 0 6.0	29 35.0 6.0
2 8.1 6.1	13 6.9 6.1

$X^2 = 11.015$

$q^2 = .840$

4 0 4.0	38 42.0 4.0
0 4.1 4.1	8 3.9 4.1

$X^2 = 8.791$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

FIG. D-11. IDENTICAL BLOCKS TEST. Hypothetical Dichotomies and Pseudo Chi-square Tests of Goodness of Fit (High Score = Sex-linked Recessive)

Fathers + Sons (N = 51)

σ_q^2 = .098

5 3.4 1.6	41 42.6 1.6
0 1.6 1.6	5 3.4 1.6

X^2 = 3.166

σ_q^2 = .196

9 5.6 3.4	32 35.4 3.4
1 4.4 3.4	9 5.6 3.4

X^2 = 7.082

σ_q^2 = .294

11 6.9 4.1	25 29.1 4.1
4 8.1 4.1	11 6.9 4.1

X^2 = 7.525

σ_q^2 = .392

10 7.5 2.5	21 23.5 2.5
10 12.5 2.5	10 7.5 2.5

X^2 = 2.433

σ_q^2 = .490

8 7.5 .5	18 18.5 .5
17 17.5 .5	8 7.5 .5

X^2 = .094

σ_q^2 = .588

8 7.0 1	13 14.0 1
22 23.0 1	8 7.0 1

X^2 = .401

σ_q^2 = .706

8 5.8 2.2	7 9.2 2.2
28 30.2 2.2	8 5.8 2.2

X^2 = 2.355

σ_q^2 = .804

7 4.2 2.8	3 5.8 2.8
34 36.8 2.8	7 4.2 2.8

X^2 = 5.298

σ_q^2 = .902

4 2.3 1.7	1 2.7 1.7
42 43.7 1.7	4 2.3 1.7

X^2 = 3.650

σ_q^2 =

X^2 =

σ_q^2 =

X^2 =

σ_q^2 =

X^2 =

Mothers + Daughters (N = 63)

σ_q^2 = .095

4 4.2 .2	53 52.9 .1
2 1.8 .2	4 4.2 .2

X^2 = .0415

σ_q^2 = .190

8 6.7 1.3	43 44.3 1.3
4 5.2 1.2	8 6.7 1.3

X^2 = .820

σ_q^2 = .286

11 8.4 2.6	34 36.6 2.6
7 9.6 2.6	11 8.4 2.6

X^2 = 2.498

σ_q^2 = .397

15 9.3 5.7	23 28.7 5.7
10 15.8 5.8	15 9.3 5.7

X^2 = 10.248

σ_q^2 = .492

19 9.3 9.7	13 22.7 9.7
12 21.7 9.7	19 9.3 9.7

X^2 = 28.715

σ_q^2 = .603

13 8.5 4.5	12 16.5 4.5
25 29.5 4.5	13 8.5 4.5

X^2 = 6.677

σ_q^2 = .698

12 7.2 4.8	7 11.8 4.8
32 36.7 4.7	12 7.2 4.8

X^2 = 8.955

σ_q^2 = .810

9 5.1 3.9	3 6.9 3.9
42 45.9 3.9	9 5.1 3.9

X^2 = 8.500

σ_q^2 = .905

6 2.8 3.2	0 3.2 3.2
51 54.2 3.2	6 2.8 3.2

X^2 = 10.703

σ_q^2 =

X^2 =

σ_q^2 =

X^2 =

σ_q^2 =

X^2 =

FIG. D-12. ENGLISH VOCABULARY TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (Low Score = Recessive)

Fathers + Sons (N = 51)

q^2_{σ} = .902

5 2.3 2.7	41 43.7 2.7
0 2.7 2.7	5 2.3 2.7

X^2 = 9.206

q^2_{σ} = .804

9 4.2 4.8	32 36.8 4.8
1 5.8 4.8	9 4.2 4.8

X^2 = 15.570

q^2_{σ} = .706

11 5.8 5.2	25 30.2 5.2
4 9.2 5.2	11 5.8 5.2

X^2 = 13.158

q^2_{σ} = .608

10 6.8 3.2	21 24.2 3.2
10 13.2 3.2	10 6.8 3.2

X^2 = 4.210

q^2_{σ} = .510

8 9.4 .6	18 18.6 .6
17 17.5 .5	8 7.4 .6

X^2 = .131

q^2_{σ} = .412

8 7.5 .5	13 13.5 .5
22 22.5 .5	8 7.5 .5

X^2 = .096

q^2_{σ} = .294

8 6.9 1.1	7 8.1 1.1
28 29.1 1.1	8 6.9 1.1

X^2 = .541

q^2_{σ} = .196

7 5.6 1.4	3 4.4 1.4
34 35.4 1.4	7 5.6 1.4

X^2 = 1.201

q^2_{σ} = .098

4 3.4 .6	1 1.6 .6
42 42.6 .6	4 3.4 .6

X^2 = .445

q^2_{σ} =

X^2 =

q^2_{σ} =

X^2 =

q^2_{σ} =

X^2 =

Mothers + Daughters (N = 63)

q^2_{σ} = .905

4 2.8 1.2	53 54.2 1.2
2 3.2 1.2	4 2.8 1.2

X^2 = 1.505

q^2_{σ} = .810

8 5.1 2.9	43 45.9 2.9
4 6.9 2.9	8 5.1 2.9

X^2 = 4.700

q^2_{σ} = .714

11 7.0 4.0	34 38.0 4.0
7 11.0 4.0	11 7.0 4.0

X^2 = 6.447

q^2_{σ} = .603

15 8.4 6.6	23 29.5 6.5
10 16.6 6.6	15 8.4 6.6

X^2 = 14.428

q^2_{σ} = .508

19 9.2 9.8	13 22.8 9.8
12 21.8 9.8	19 9.2 9.8

X^2 = 29.496

q^2_{σ} = .397

13 9.3 3.7	12 15.8 3.8
25 28.7 3.7	13 9.3 3.7

X^2 = 4.335

q^2_{σ} = .302

12 8.6 3.4	7 10.4 3.4
32 35.4 3.4	12 8.6 3.4

X^2 = 4.126

q^2_{σ} = .190

9 6.7 2.3	3 5.2 2.2
42 44.3 2.3	9 6.7 2.3

X^2 = 2.629

q^2_{σ} = .095

6 4.1 1.9	0 1.9 1.9
51 52.9 1.9	6 4.1 1.9

X^2 = 3.729

q^2_{σ} =

X^2 =

q^2_{σ} =

X^2 =

q^2_{σ} =

X^2 =

FIG. D-13. ENGLISH VOCABULARY TEST. Hypothetical Dichotomies and Chi-square Tests of Goodness of Fit (High Score = Recessive)

Fathers + Daughters (N = 62)

$q_{\sigma}^2 = .138$

16 14.4 1.6	7 8.6 1.6
37 39.0 2.0	2 0 2

$\chi^2 = .58$

$q_{\sigma}^2 = .204$

18 15.4 2.6	10 12.6 2.6
31 34.0 3.0	3 0 3

$\chi^2 = 1.24$

$q_{\sigma}^2 = .319$

19 15.3 3.7	16 19.8 3.8
23 27 4.0	4 0 4

$\chi^2 = 2.22$

$q_{\sigma}^2 = .437$

17 13.9 3.1	24 27.1 3.1
18 21.0 3.0	3 0 3

$\chi^2 = 1.47$

$q_{\sigma}^2 = .575$

14 11.3 2.7	33 35.7 2.7
12 15.0 3	3 0 3

$\chi^2 = 1.45$

$q_{\sigma}^2 = .677$

12 9.1 2.9	39 42.0 3.0
8 11.0 3.0	3 0 3

$\chi^2 = 1.96$

$q_{\sigma}^2 = .815$

9 5.5 3.5	47 50.5 3.5
2 6.0 4.0	4 0 4

$\chi^2 = 5.14$

$q_{\sigma}^2 = .937$

4 1.9 2.1	56 58.1 2.1
0 2.0 2	2 0 2

$\chi^2 = 4.40$

$q_{\sigma}^2 =$

$\chi^2 =$

$q_{\sigma}^2 =$

$\chi^2 =$

$q_{\sigma}^2 =$

$\chi^2 =$

$q_{\sigma}^2 =$

$\chi^2 =$

Mothers + Sons (N = 50)

$q_{\sigma}^2 = .100$

0 0 0	5 5.0 0
34 34.2 0.2	11 10.8 0.2

$\chi^2 = .005$

$q_{\sigma}^2 = .160$

1 0 1	7 8.0 1.0
29 30.0 1.0	13 12.2 1.0

$\chi^2 = .242$

$q_{\sigma}^2 = .240$

3 0 3	9 12.0 3.0
23 25.5 2.5	15 12.5 2.5

$\chi^2 = 1.50$

$q_{\sigma}^2 = .340$

2 0 2.0	15 17.0 2.0
19 20.9 1.9	14 12.1 1.9

$\chi^2 = .706$

$q_{\sigma}^2 = .440$

4 0 4	18 22.0 4.0
13 16.8 3.8	15 11.2 3.8

$\chi^2 = 2.88$

$q_{\sigma}^2 = .520$

4 0 4	22 26.0 4
10 14.0 4	14 10.0 4

$\chi^2 = 3.36$

$q_{\sigma}^2 = .640$

4 0 4	28 32.0 4
6 10.0 4	12 8.0 4

$\chi^2 = 4.10$

$q_{\sigma}^2 = .800$

2 0 2	38 40.0 2
3 5.3 2.3	7 4.7 2.3

$\chi^2 = 2.22$

$q_{\sigma}^2 = .920$

2 0 2	44 46. 2
0 2.1 2.1	4 1.9 2.1

$\chi^2 = 4.51$

$q_{\sigma}^2 =$

$\chi^2 =$

$q_{\sigma}^2 =$

$\chi^2 =$

$q_{\sigma}^2 =$

$\chi^2 =$

FIG. D-14. **HEIGHT.** Hypothetical Dichotomies and Pseudo Chi-square Tests of Goodness of Fit (High Score = Sex-linked Recessive)

Fathers + Daughters (N = 62)

$q^2 = .104$

18 13.5 4.5	2 6.4 4.4
38 42.0 4.0	4 0 4

$X^2 = 4.91$

$q^2 = .176$

22 15.1 6.9	4 10.9 6.9
29 36.0 7.0	7 0 7

$X^2 = 8.88$

$q^2 = .266$

24 15.5 8.5	8 16.5 8.5
22 30.0 8.0	8 0 8

$X^2 = 11.17$

$q^2 = .338$

24 15.1 8.9	12 21.0 9
17 26.0 9.0	9 0 9

$X^2 = 12.22$

$q^2 = .458$

22 13.6 8.4	20 28.4 8.4
11 20.0 9	9 0 9

$X^2 = 11.72$

$q^2 = .575$

17 11.3 5.7	30 35.7 5.7
9 15.0 6.0	6 0 6

$X^2 = 6.18$

$q^2 = .677$

14 9.1 4.9	37 42.0 5.0
6 11.0 5.0	5 0 5

$X^2 = 5.51$

$q^2 = .787$

9 6.2 2.8	46 48.8 2.8
4 7.0 3.0	3 0 3

$X^2 = 2.71$

$q^2 = .874$

6 3.8 2.2	52 54.2 2.2
2 4.0 2.0	2 0 2

$X^2 = 2.36$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

Mothers + Sons (N = 50)

$q^2 = .120$

1 0 1	5 6.0 1
32 32.7 .7	12 11.3 .7

$X^2 = .225$

$q^2 = .180$

2 0 2	7 9.0 2
27 28.8 1.8	14 12.2 1.8

$X^2 = .823$

$q^2 = .240$

3 0 3	9 12.0 3
23 25.5 2.5	15 12.5 2.5

$X^2 = 1.50$

$q^2 = .340$

6 0 6	11 17.0 6
15 20.9 5.9	18 12.2 5.8

$X^2 = 6.54$

$q^2 = .440$

7 0 7	15 22.0 7
10 16.9 6.9	18 11.2 6.8

$X^2 = 9.17$

$q^2 = .560$

6 0 6	22 28.0 6
7 12.6 5.6	15 9.4 5.6

$X^2 = 7.11$

$q^2 = .680$

7 0 7	27 34.0 7
2 8.8 6.8	14 7.3 6.7

$X^2 = 12.85$

$q^2 = .820$

4 0 4	37 41.0 4
1 4.7 3.7	8 4.3 3.7

$X^2 = 6.49$

$q^2 = .920$

2 0 2	44 46.0 2
0 2.1 2.1	.4 2.0 2

$X^2 = 4.19$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

$q^2 =$

$X^2 =$

FIG. D-15. WEIGHT. Hypothetical Dichotomies and Pseudo Chi-square Tests of Goodness of Fit (High Score = Sex-linked Recessive)